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By G. H. Dury, M.A. Ph.D. F.G.S.

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Chapter One

CLIMATE

THIS book is about physical geography. It deals with the form of the ground, the natural agencies that affect the land, with the air, and with the ocean waters and their movement. In other words, it studies the background to Man's activities. The geography of the world is a balanced study involving both Nature and Man. It is only for the sake of convenience that two books in this series treat these two aspects of geography, one under the heading of Physical Geography and the other under that of Human Geography. Physical geography is concerned with the geographical background, human geography with where and how men live. In a given physical setting, however, several ways of life are possible. This is why the physical study comes first. We first examine the nature of the land, and go on to see how men adapt themselves to their surroundings, make use of natural advantages, and overcome natural difficulties.

Physical geography falls into two parts—the land itself on the one hand, and climate on the other. Climate is here taken first, because it profoundly affects the type of vegetation and of soil, and provides the agencies which carve the landscape. Climate determines whether the land is eroded by rain and rivers, by frost, ice, and snow, or by wind and sun. Differences of climate make the scenes of deserts, coniferous forest lands, or snowfields look very different from one another.

In addition, climate has a great effect on the things that men can do. It sets limits, for example, to the profitable growing of crops. Britain has a climate too cold for the growing of rubber, pineapples, and oranges. Vast expanses of desert are too dry for any crops of commercial value; even if water can be brought to them, it is water which has fallen somewhere at some time as rain. Climate affects the amount of clothing that people wear; it influences human energy and capacity for prolonged hard work, and affects the design of buildings; it determines whether houses need to be heated, whether rivers and water-pipes are liable to freeze, and whether winter brings snow or not.

There is another reason for beginning with climate. In most parts of the world there is a noticeable change in climate from one season to another. In some places, indeed, the weather is rarely the same for two days together. Now, changes in weather and in climate have an influence on men, animals, and plants. Many of the world's people must arrange their lives according to the seasons.

Changes in the weather from day to day, or in climate from one season to another, occur far more quickly than changes in the landscape. Within the span of a human lifetime the physical surface of the earth changes very little. It seems, indeed, to provide an almost permanent background to the constantly changing scene of weather and to the rhythm of the seasons. We shall see later that the Earth's surface does in fact undergo very marked changes, but that most of these are very slow. We can normally observe only those rapid changes that include earthquake tremors, the destruction of part of the coast, or the speedy growth of a delta. Although such occurrences can be extremely important in human geography, they are but trivial incidents in the lengthy history of the physical landscape. In contrast to this slow rhythm, a single year is enough for a complete cycle of seasonal change in climate.

Climatic elements

We start then with climate and weather. The climate of a place is the condition of the air there during the year. It depends on air temperature, moisture in the air, air pressure, and winds. These are all *climatic elements,* and as such will be discussed in the three succeeding chapters.

They are also, however, elements of weather. The difference between weather and climate is that weather concerns but a short span of time, while climate relates to a longer period. Again, climate has to do with average conditions while weather refers to single happenings. We speak about the state of the weather at the moment, the kind of weather we had last week, or even of the weather of a particular season in one year. For instance, the summer of 1954 brought unusually wet and cool weather to much of Britain. Some farmers lost their grain and hay; many cricket matches were unfinished because of rain; holidays were spoiled, and rainy weather continuing into the following autumn caused floods. But in a run of years such wet seasons are offset by dry ones. Although the summer of 1954 was rainy, the month of August was very dry in 1947, 1948, and 1949, and the whole summer of 1955 brought little rain. Some farms suffered in these years, for the grass was parched, and in places there was not enough water for the cattle to drink. It remains, however, true to say that very wet and very dry years are the exception in Britain, and balance one another in the average figures. It is average figures that justify the description of Britain's climate as one of cool summers and mild winters, with adequate rain well distributed through the year.

Climatic controls

Several factors determine climate. They cause variations in the elements of climate—changes, that is, of temperature, changes in the amount of moisture in the air, falls of rain and snow, changes in air pressure and in the flow of winds. The factors determining these changes are *climatic controls.* They include heating by the sun, systems of air pressure, distribution of land and sea, relief of the land, and ocean currents. These also are discussed in the next two chapters, along with the elements of climate.

Heating by the sun will be taken first, for it is solar energy which ultimately causes those happenings which we class together as weather. Incoming energy and outgoing radiation combine to produce systems of air pressure which in turn are responsible for winds. It will be seen that the distribution of land and ocean, the relief of the land-surfaces, and the nature and direction of ocean currents greatly modify weather and climate, and it is for this reason that they are classed as climatic controls.

Chapter Two

AIR TEMPERATURE AND AIR PRESSURE

1 Air temperature

An envelope of air—the atmosphere—covers the Earth. Although the atmosphere is two hundred miles thick, weather and climate are produced in a layer less than ten miles thick which lies next to the Earth's surface.

Heating of the atmosphere. The air is warmed from below. Short-wave radiation from the sun, mainly in the form of light-rays, enters the atmosphere, and part of it reaches the surface of the Earth. The surface is warmed and emits rays of heat. As these are of longer wavelength than the light-rays they cannot easily pass through the air. Consequently heat is trapped. This explains why the heating is confined to a shallow layer of air at the base of the atmosphere. Eventually, of course, the heat escapes again into space, but a balance is maintained between incoming and outgoing radiation, so that in the long run the average temperature of the whole atmosphere changes very little.

Temperatures in the sunshine are higher than those in the shade ; temperatures close to the ground vary much more than those a few feet above it. In order to avoid the effects of direct sunlight and of very strong heating and cooling near the ground, we use in describing climate *shade temperatures*, taken at about four feet above ground level. Again, the air is usually cooler

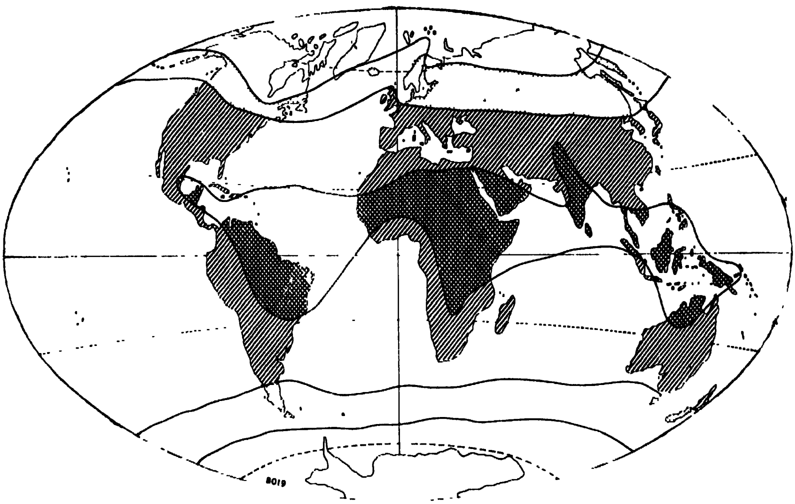


Fig. 1 MEAN ANNUAL TEMPERATURE, CORRECTED TO SEA-LEVEL.

by night than by day. We therefore use *mean*, i.e. average figures, often the mean temperature for a given month.

Now look at the map of mean temperature for the year (Fig. 1). Some parts of the world are obviously warmer than others. Near the Equator temperatures above 80° F occur, whereas near the Poles the figure is below 40° F. Two causes help to explain the contrast:

(i) the curvature of the Earth's surface
(ii) the filtering of the sun's rays by the atmosphere

(i) *Effect of the Earth's curvature.* This is also known as the effect of latitude. Between the Tropics the noonday sun is always high in the sky; its rays are never far from vertical and they heat the ground strongly (Fig. 2). Near the Poles the sun is never high in the sky, even at noonday in midsummer. Its rays always fall obliquely, spreading widely on the surface and giving little warmth, and the reflected rays are scattered and weak.

(ii) *Effect of filtering by the atmosphere.* This factor works in the same direction, increasing the coldness of polar regions. Where the sun is nearly overhead its rays take a short path through the atmosphere, and suffer the minimum loss of strength. But

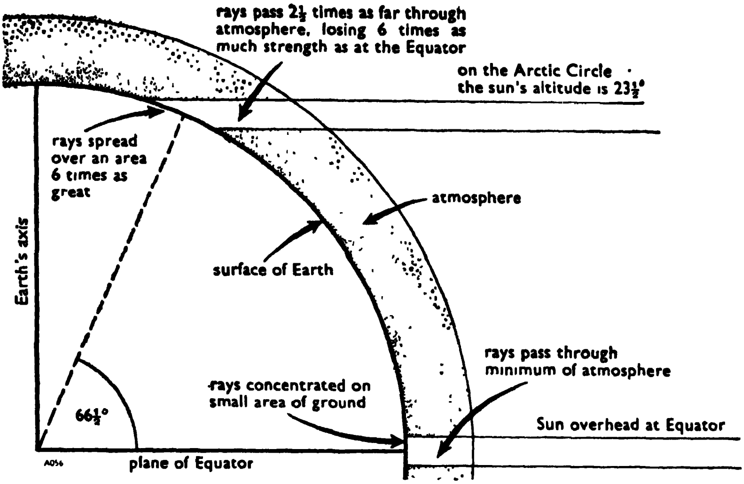


Fig. 2 EFFECTS OF THE ATMOSPHERE AND OF THE EARTH'S CURVATURE on the intensity of solar radiation at the surface.

where it is low in the sky the rays must filter through a great thickness of air (Fig. 2), and are weak by the time that they reach the ground.

Influence of relief on temperature. It is well known that the air is colder at high than at low levels—very high mountains are snow-capped the whole year round, even at the Equator itself, for they rise far into the cold air (Pl. 1). Mean temperature decreases by about 1° F for every 300 feet of ascent. If the average sea-level temperature is 70° F, the air at the top of a mountain in the immediate vicinity 15,000 feet high would be at about 20° F, i.e. well below freezing point. In fact, the lower limit of permanent snow—*the snowline*—lies near 20,000 feet above sea-level near the Equator.

Temperatures are said to be *reduced to sea-level* when they are increased by 1° F for every 300 feet of height. Such adjusted figures are often used in describing climates and in drawing maps of temperature distributions, as they are far more convenient than actual figures. Lines of equal temperature plotted on a map are *isotherms*: the pattern of actual isotherms is not only complicated, it is also inconveniently like a map of relief; but sea-level isotherms arrange themselves in a simple pattern which is easy to read, as can be seen in an atlas or in Fig. 1. Since most of the world's people live less than 300 feet above sea-level the corrected mean figures differ very little from actual ones for many thickly populated areas, but in studying highland districts allowance must always be made for the cooling effect of altitude.

Seasons. Over most of the Earth the average air temperature rises and falls with the seasons. The changes are due to the character of the Earth as a planet, a satellite of the sun.

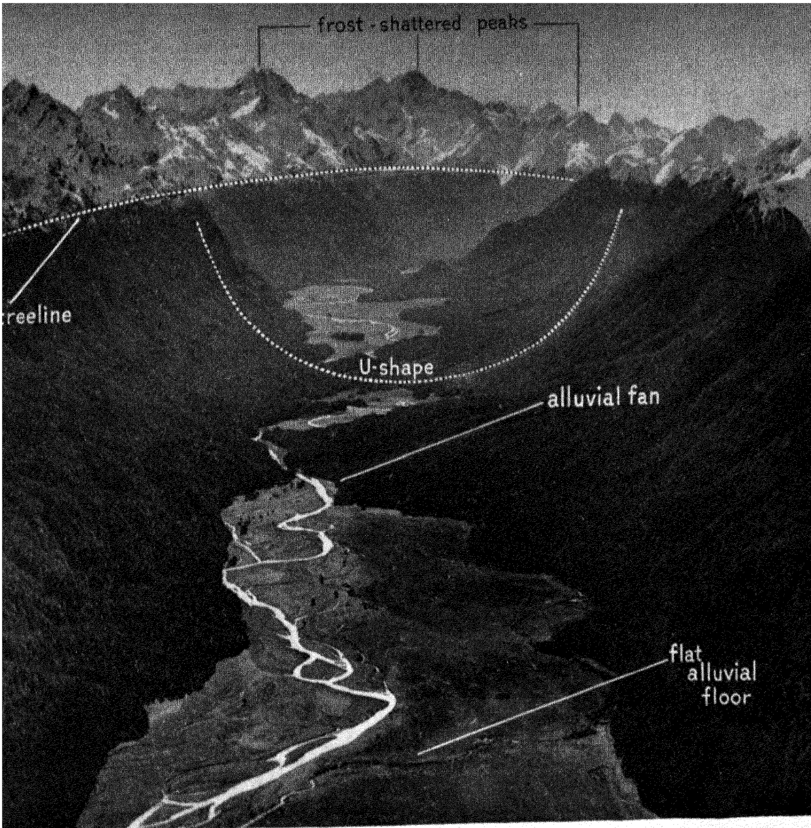
(i) *Varying length of daylight.* The Earth revolves round the sun, about a hundred million miles away from it, once a year. It also spins (rotates) on its axis once a day. This axis is tilted. In summer in the northern hemisphere, the northern end of the axis—the North Pole—is tilted towards the sun, and at this season places north of the Equator get more than twelve hours' daylight and less than twelve hours' night. Near the North Pole at midsummer the sun never sets (Fig. 3). The effect of the tilt is strongest in middle latitudes. We have seen that in polar regions the sunshine is always weak and temperatures low ; on the Equator nights and days are always 12 hours long, and the power of the sun's rays changes little through the year. But in middle latitudes in summer a great deal of radiation comes in during the long days, so that the air becomes warmer and warmer.

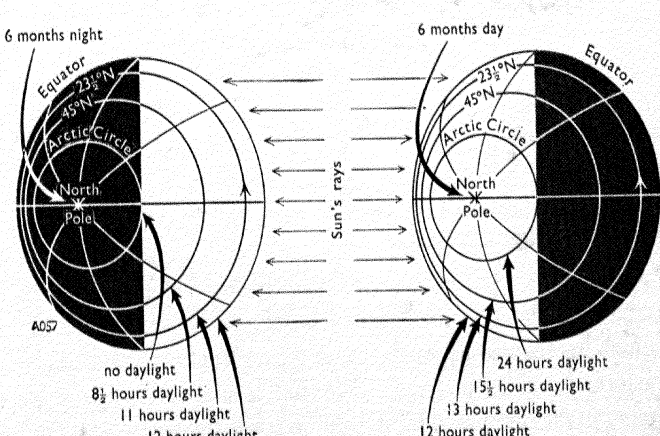
Six months later the position is reversed (Fig. 3). The Earth has travelled half-way along its annual path round the sun. The northern end of the axis is tilted away, and it is winter in the northern hemisphere. Nights in high and middle latitudes are long. During the short days little radiation is received from the low sun, and the air becomes progressively cooler.

(ii) *Temperature range.* The mean annual range of temperature —often called the *annual range* for short—is the difference between the mean temperatures for the warmest and coldest months.

***Plate* 1** MOUNTAINS RISING ABOVE THE SNOWLINE, **Eglinton Valley, South Island, New Zealand. In this locality the treeline and the snowline roughly coincide. The physical features which are labelled are typical of glaciated highland (see Chapter 18). The flat spread of alluvium in the bottom of the trough is composed largely of rock-waste melted out of the glacier and now being worked over by the river.**

***Fig.* 3** EFFECT OF THE TILT OF THE EARTH'S AXIS **on length of daylight at different seasons.**


frost-shattered peaks
treeline
U-shape
alluvial fan
flat alluvial floor


6 months night
Equator
23½°N
45°N
Arctic Circle
North Pole
no daylight
8½ hours daylight
11 hours daylight
12 hours daylight
Sun's rays
6 months day
Equator
23½°N
45°N
Arctic Circle
North Pole
24 hours daylight
15½ hours daylight
13 hours daylight
12 hours daylight
A057

These are usually January and July, one or other being warmest according to the hemisphere—the southern hemisphere naturally has its winter during the northern summer.

Winds and ocean currents. Air temperature does not depend only on the strength of incoming radiation and the length of daylight. Heat is transported by currents in the air (i.e. winds) and by ocean currents. Winds blowing inland off a warm sea keep the temperature high. Again, land surfaces heat and cool far more rapidly than does the ocean surface. Once more the effect is greatest in middle latitudes, where the sea surface remains warm when the lands are already chilled by the advancing winter. Places in the interiors of great landmasses, where seasonal heating and cooling are most rapid, have large annual ranges of temperature, whereas at places with onshore winds from warm seas the winters are mild and the annual range is small. A useful contrast can be drawn between *maritime climates*, strongly influenced by the sea, and *continental climates*, dominated by the climatic influence of the land.

2 Temperature and pressure

Seasonal changes in temperature affect the flow of winds, for winds are due to differences of air pressure, and this in turn is influenced by air temperature.

Air has weight. It is held on the globe by the force of gravity, and exerts pressure on the surface. The pressure is measured in *millibars* : average pressure is about 1,013 millibars, but for the sake of simplicity pressure above 1,012 millibars is called high pressure, while lesser values indicate low pressure. As with temperature, recordings of pressure are reduced to sea-level before they are plotted on a map. Lines of equal pressure, such as those in Fig. 6, are *isobars*.

Air at low levels is under pressure from all the air above it (Fig. 4). At great heights, as there is little air above, the pressure is much less than at sea-level. Now, air can easily be compressed. It contracts under pressure. The fact is simply illustrated by forcing in the piston of a bicycle pump while the outlet is blocked

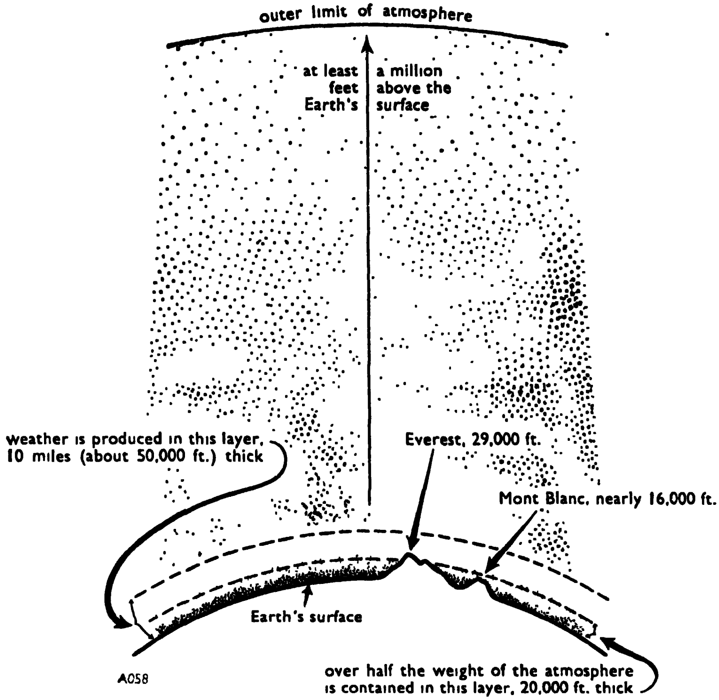


Fig. 4 ATMOSPHERIC PRESSURE AND HEIGHT ABOVE SEA-LEVEL.

—the air trapped in the pump can easily be reduced to less than half its original volume. If the test is made several times in succession the lower end of the pump becomes warm. Heat has been set free from the air under pressure. Conversely, if air expands it must absorb heat to provide the energy to keep it expanded. Most of the heat comes from the air itself, so that when air expands under reduced pressure the temperature falls. This is why air at high levels is cold—it is far from the source of heat (the ground) and is only weakly compressed by the overlying air. Here is the reason for a decrease of 1° F in temperature with every 300 feet of height.

Topics for discussion

1 Keep a record of lighting-up time in your home district, and illustrate the change from week to week by means of a graph.

2 Make a similar graph to show changes in the times of sunrise and sunset.

3 Calculate the angular height above your local horizon of the sun at midsummer day, at midwinter, in mid-autumn, and in mid-spring. Check the results of your calculations by observation, using a vertical stick and measuring the length of its shadow at noon (G.M.T.).

4 Keep records of air-temperature, taking observations at the same time each day. Plot the results on a graph. Determine the mean temperature for individual months.

5 Using a maximum and minimum thermometer, keep records of daily range of temperature. Find out whether the range is greater on calm days or on windy days, and explain the results you obtain.

6 Explain as fully as possible why aircraft designed to fly at great heights have their cabins pressurised and heated.

7 Using atlas maps, describe and account for the differences between sea-level isotherms and actual isotherms for the British Isles.

8 Find out the annual range of temperature of your home district. Compare it with ranges for places nearer to the sea or farther inland, and account for any differences you notice.

Chapter Three

WIND SYSTEMS AND OCEAN CURRENTS

AIR pressure is not constant at any one place, nor is average pressure the same over the whole Earth. Day-to-day changes in pressure are important in the study of weather, while average distributions illuminate the problems of climate. As Fig. 5 shows, the distribution of average sea-level pressures reveals some belts where the values are low and some where they are high. This state of affairs has much to do with the flow, direction, and strength of winds, for winds are nothing more than air which tends to flow from high pressure to low. Three things should be borne in mind :

(i) the air is heated by radiation from the sun
(ii) land heats and cools more quickly than water
(iii) the Earth is rotating

These factors help in the understanding of the great wind systems to which we now turn.

I Systems of wind and pressure

(i) *The Trade Winds and associated pressure-belts.* Powerful heating in equatorial regions makes the air there expand and become less dense. It therefore tends to rise and to flow outwards at higher levels. A system of low pressure is established—the *equatorial low-pressure belt,* also called the Doldrums.

Winds blow into the equatorial low pressure from each side. Like all winds, they are deflected by the effect of the Earth's rotation—to the right in the northern hemisphere and to the left in the southern. They constitute the *Northeast* and *Southeast Trade Winds* (Fig. 5). At times the two wind systems are in contact within the Doldrum belt. Air then rises along their common boundary—the *inter-tropical front*—giving additional rain to the generally wet lands below.

The Trade Winds are supplied from the belts of *sub-tropical high pressure.* In these areas the air is slowly sinking, being compressed and becoming warm and dry as it does so. The high pressure is maintained by the inflow of air at high levels—some of the air, in fact, which we have seen rising and flowing

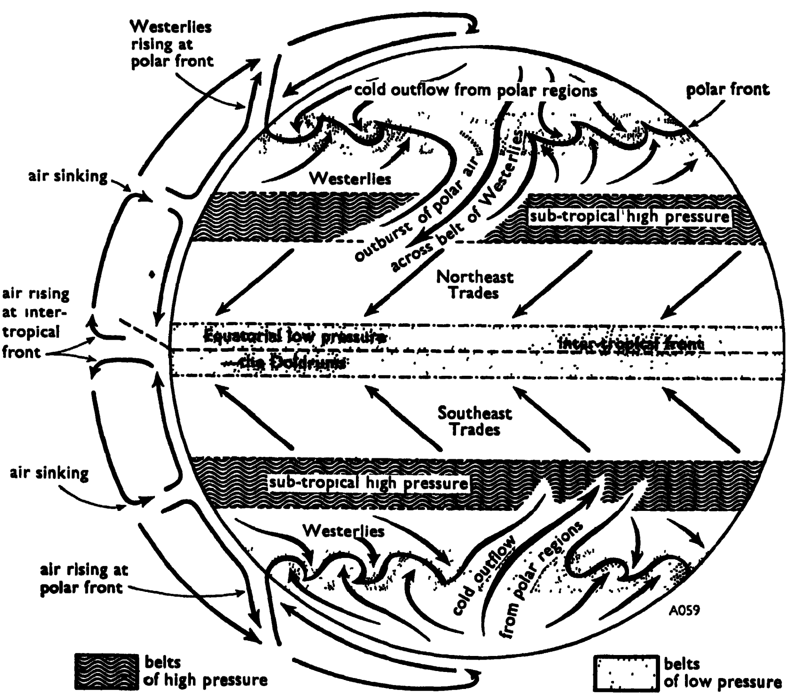


Fig. 5 THE GENERAL CIRCULATION OF THE ATMOSPHERE.

outward from equatorial regions. Because of the deflection to left or right, according to the hemisphere, this air cannot flow indefinitely towards the Poles. It tends to accumulate near the Tropics, setting up the belts of high pressure which feed the Trades.

(ii) *The westerlies.* Poleward of the sub-tropical highs lie two belts of westerlies. They, too, are fed from the high-pressure systems. They are typically stormy, with travelling low-pressure systems within them (see pp. 64–7). On their poleward side they are separated from the cold, outflowing air of polar regions by the *polar front*—the boundary between the two wind systems. The moist, warm westerlies tend to rise over the denser polar air, condensing their moisture and giving frequent rain to western coastlands in middle latitudes.

(iii) *Winds of Polar regions.* The outflow of wind from high latitudes is maintained by an inflow at high levels (Fig. 5), partly in the form of the rising westerlies and partly as high-level currents. The accumulation of air must be relieved from time to time; it results in occasional outbursts of polar air which sweep right across the belts of westerlies towards the tropics.

2 Contrasting effects of land and sea

So far the major belts of pressure and winds have been discussed as if the distribution of land and sea had no effect on them. But remembering the rapid heating and cooling of the land surface, and the much slower changes in sea surface temperatures, we can see that seasonal alterations are bound to occur.

(i) *The northern winter.* In winter in the northern hemisphere the large land areas cool quickly, chilling the overlying air which contracts and increases in density. Two seasonal high-pressure systems appear over North America and Asia (Fig. 6*a*). Over the warmer ocean surfaces of the North Atlantic and North Pacific two deep and extensive areas of low pressure are to be seen. The sub-tropical belt of high pressure is scarcely visible

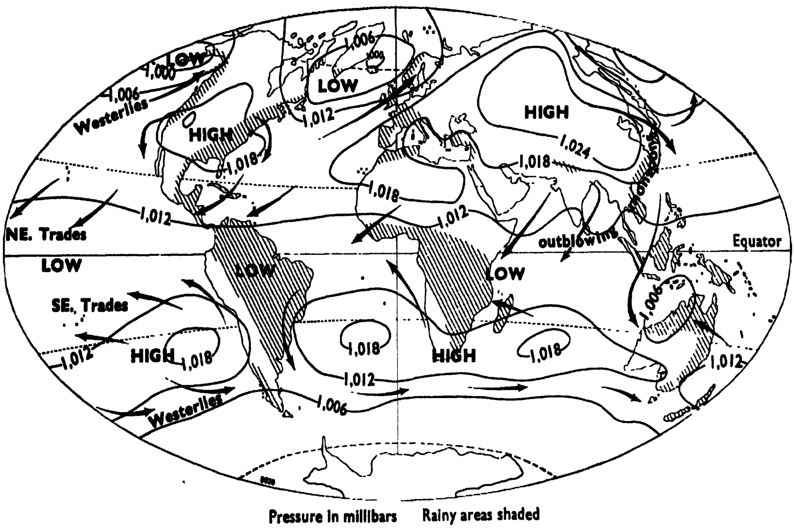


Fig. 6a PRESSURE AND WINDS DURING THE NORTHERN WINTER.

in the northern hemisphere. The flow of winds is accordingly changed. Because of deflection, winds tend to blow *round* the pressure systems. Western Europe receives much mild air from the southwest, eastern Asia cold air from the northeast.

In the southern hemisphere, which is experiencing its high-sun season, the sea surfaces are cooler than the lands. Three systems of high pressure lie over the three southern oceans, giving northerly (warm) winds on the eastern sides of the lands, and southerly (cool) winds on the western sides.

(ii) *The northern summer.* When the overhead noonday sun is north of the Equator the great northern landmasses are warmed. Deep lows develop over the Thar Desert of India, over inner Asia, and over the arid belt of North America, while two extensive systems of high pressure spread widely across the Pacific and Atlantic Oceans (Fig. 6*b*). These highs represent a northward extension of the sub-tropical high-pressure belt.

In the southern hemisphere the lands are less extensive than in the northern, and this fact is reflected in smaller seasonal changes of pressure. Nevertheless, during the southern winter the low-pressure systems disappear, and a system of high pressure, with outblowing winds, develops over the interior of Australia.

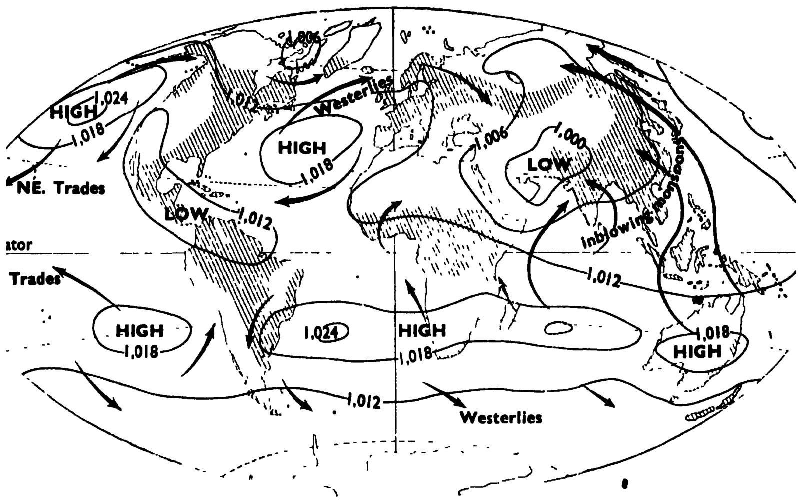


Fig. 6b PRESSURE AND WINDS DURING THE NORTHERN SUMMER.

(iii) *Monsoons.* The most striking disturbance of the systems of wind and pressure is the seasonal reversal of winds in eastern Asia. This, the greatest landmass of all, is the site of low pressure with associated inblowing winds in summer, and of high pressure with outflowing air in winter. These winds, the *monsoons*, result in a climate with only two seasons that will be further described in Chapter 7.

(iv) *Cells of high and low pressure.* We see, then, that the effects of the distribution of land and sea are to break up the major pressure belts into separate cells. The most conspicuous changes are in middle latitudes, where pressures are generally low over the land in summer and low over the sea in winter. The cellular arrangement produces very different climatic effects on eastern and western sides of the lands.

Consider the coasts of the North Atlantic Ocean near the Tropic of Cancer. On the western (American) side, in the West Indies and Central America, the warm oceanic Trade Winds blowing round the sub-tropical high pressure are always onshore. On the eastern (African) side, however, winds come from the north. Blowing towards the Equator, they are being warmed all the time; they arrive as drying winds, and even if they blow

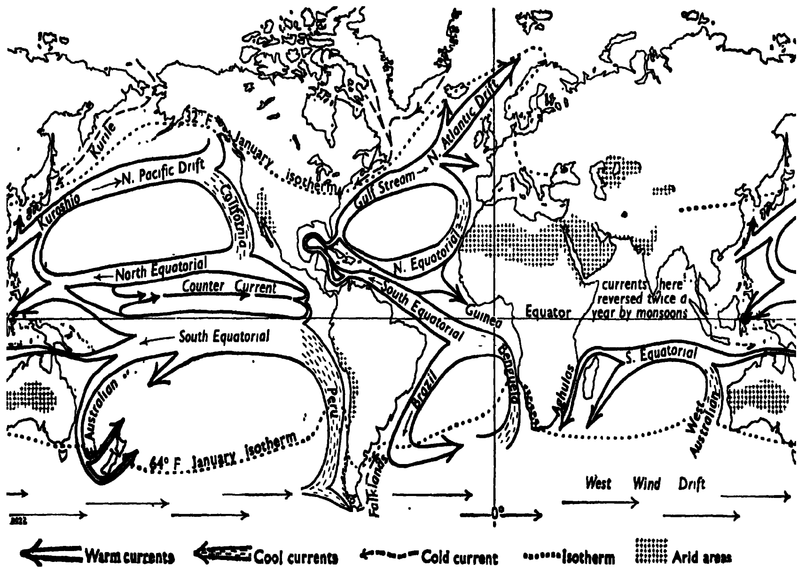


Fig. 7 MAJOR OCEAN CURRENTS.

over the land they can give little rain. This is why the desert can extend right to the coast, contrasting strongly with the rain-forest and plantations of the far side of the ocean.

Similar contrasts exist in similar situations elsewhere—compare the eastern and western sides of South America, South Africa and Australia. In all these lands the Tropic of Capricorn passes through desert on the western side and through a rainy region on the eastern.

3 Ocean currents

Heat and cold are transported by ocean currents as well as by winds. Generally speaking, the currents of water tend to flow in the same direction as that of the overlying wind-systems. This is to be expected, for the winds help to keep the currents moving. It follows that the climatic effects of the winds are increased by those of the ocean currents—where the winds bring warmth, ocean currents bring still more.

(i) *The North Atlantic* (Fig. 7). In the North Atlantic surface water is driven westwards by the Trade Winds. It passes through the Caribbean Sea or skirts the West Indies, emerging near the tip of Florida as the Gulf Stream. This strong, warm current carries tropical waters into middle latitudes. Off Newfoundland it swings northeastwards as the North Atlantic Drift—a skin of warm water which moves towards Europe in the belt of westerlies. Here is the source of warmth for the onshore winter winds of northwest Europe, and the reason why Norway is so much warmer than Greenland.

Part of the Drift eventually sinks beneath the cold but less salty waters of the Arctic. Another branch—the Canaries Current—turns southward off Spain. Like the winds which follow the same direction in summer, it arrives as a cold stream off the western coast of Africa. Any winds which blow from ocean to land in this area are, therefore, cool; becoming warmer over the desert, they bring no rain and are indeed able to evaporate moisture.

(ii) *The South Atlantic.* As the map indicates, the South Atlantic has a similar system of ocean currents, except that the circulation—taking place in the southern hemisphere—is left-handed. A cool current flows northward off Africa—the Benguela Current, comparable to the Canaries Current. The warm Brazil Current on the other side of the ocean is weaker than the corresponding Gulf Stream, for the shoulder of Brazil diverts some water from the South to the North Atlantic.

(iii) *The Peru Current.* This, the greatest cold current of all, receives much water from cold regions—note how South America extends far towards the Antarctic. The moving water tends to swing away from the coast, under the influence of deflection to the left, and still colder water wells up from moderate depths close inshore. It is not surprising that the western coastlands of tropical South America remain arid, for any winds blowing onshore are heated and dried over the land.

(iv) *Other major currents.* What has already been said is sufficient to explain why there should be a warm current, the Kuroshio or Black Stream, in the North Pacific. Flowing in the western side of the basin, it corresponds to the Gulf Stream in the Atlantic, and like it is prolonged by a warm drift to the east. The Californian coast, like the Saharan coast of Africa, is affected by a cold current. One final example should be noted—the Labrador Current, which comes south towards Newfoundland and inserts very chilly water between the Gulf Stream and the mainland. The mixing of air over the two adjacent streams is responsible for frequent and dense fogs.

Topics for discussion

1 Keep a record of wind-direction, plotting the results in the form of a wind-rose.

2 A wind-rose maintained for a term should be enough to indicate the direction of the prevailing wind. What is this direction, and how do you account for it ?

3 Maintain records of the type of weather and incorporate them in your wind-rose. What wind-directions are chiefly associated with (*a*) thick cloud and rain ; (*b*) skies with little or no cloud ; (*c*) high temperatures in the winter months ; (*d*) very low temperatures in the winter months ?

4 Using the Daily Weather Report or the maps published in *The Times* and the *Manchester Guardian*, plot the courses of travelling low-pressure systems across or near to the British Isles. A record kept for a term will show the usual direction of travel. What is this direction, and how do you account for it ?

5 Using an atlas map of sea-level isotherms, find out how the mean January temperature of your home area compares with the mean January temperatures of places in the same latitude in North America and in the heart of Asia. State the extent of the differences you notice, and explain them as fully as possible.

6 The sea surface off the coasts of Britain is considerably warmer in autumn than in spring. Why is this ?

7 Draw a map of the world, showing on it the great warm ocean currents, the areas of heavy rainfall, and the areas where the prevailing winds are onshore. Discuss the conclusions which may be drawn from your map.

Chapter Four

WATER IN THE AIR

MOISTURE can be present in the air in two forms—as a gas, i.e. water vapour, or as the tiny droplets which make up fog and cloud. Many of the most noticeable things about the weather depend on atmospheric moisture—rain, hail, snow, clouds and fog that obscure the sun, and frost in its various forms. Without this moisture there would be no rivers and no soil moisture ; life on land could not exist, for water is necessary to all living things.

1 Absorption and release of moisture

In some respects moisture in the air is the most important of all climatic elements. We began this account in Chapter 2 with temperature, however, because temperature controls the amount of water vapour that air can hold.

Evaporation. When water changes its state from liquid to gas, and passes into the air, it is said to evaporate. As warm air can hold more water vapour than a similar volume of cold air, warm winds are often drying winds. The principle is applied in the electric hair-dryer, which supplies a blast of warm air capable of absorbing moisture. On a larger scale experiments have been made in drying waterlogged sports fields with the hot exhaust from jet engines.

Air pressure and winds must also be taken into account. While temperature controls the *possible* amount of water vapour in the air, the *actual* amount depends on where the air has been. The sinking air of high-pressure systems is being compressed; its temperature rises and it can take up more moisture. Again, winds from the sea are likely to be moist, for they have evaporated moisture before they reach the land, but winds travelling far across dry land surfaces are themselves likely to be dry.

Condensation. As air is cooled it loses some of its capacity to hold water vapour. If cooling goes far enough the *condensation point* is reached—the air is saturated and some of its vapour must condense into liquid. Cooling may be due to a cold surface below—i.e. a cold land or a cold ocean current—or to rising, either over high ground or over a body of cold, dense air. Remember that air pressure falls off with height. If air is made to rise the pressure on it is reduced. It expands and its temperature drops.

(i) *Fog, dew, and frost.* Winter fogs in Britain occur when mild, damp air comes in from the western ocean and passes over frozen ground. Cooling below saturation point makes the air condense great quantities of moisture in the form of fog. Similar effects at sea have already been mentioned—we have seen that air off the Gulf Stream can be chilled when it passes over the Labrador Current. Fogs also form in still air, when the sky is clear and heat can escape from the ground during a long winter night. The overlying air is chilled and becomes foggy. This is the explanation of the persistent fogs which become polluted by smoke in industrial districts (Fig. 8).

Dew is formed by condensation on cold solid objects—the surface of the ground, plants, and buildings. Frost occurs when the condensed water is frozen. Rapid freezing traps air in the ice and produces white frost; slow freezing allows the air to escape and the ice formed is clear and glassy.

(ii) *Cloud* is due to condensation of tiny droplets above ground level in rising, expanding, and therefore cooling, air. Think of

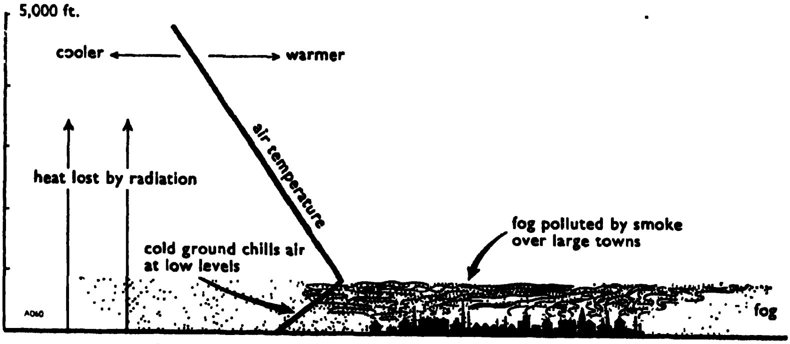


Fig. 8 RADIATION FOG AND ITS POLLUTION BY SMOKE.

a sunny summer day : some parts of the land surface warm more quickly than others—bare rock and grain fields become hotter than marshes or forest. Over the hotter places currents of warm air rise. If they go far enough they are cooled below saturation point and their moisture condenses into droplets. Cloud forms. Now when moisture is condensed heat is released—the *latent* heat that was originally needed to evaporate the water. With this additional supply of heat the rising air expands still more. It is far less dense than the surrounding air and rises faster than before. If the supply of moisture is small the clouds can only grow to moderate sizes, but if the air is damp a violent uprush takes place and thunder clouds may reach as high as seven miles above ground level.

Similarly, when air is rising over a barrier, condensation releases heat energy and the air expands and rises faster. In damp air dense cloud may again be expected.

(iii) *Rain, snow, and hail.* The water droplets in a cloud are so minute that the gentlest movement of air keeps them aloft. But if they come together into raindrops they must fall to the ground. There are three types of rain :

(*a*) convectional (*b*) relief (*c*) cyclonic

(*a*) *Convectional rain.* This is thunder-rain, due to the turbulent uprise of currents of damp air. The up-currents are set off, as explained above, by local heating of the land surface. In the powerful up-currents of a thundercloud raindrops grow to a large size. They are repeatedly broken up as they fall, releasing tiny electric charges into the surrounding air. Electric tension is established between different parts of a thundercloud, or between the cloud and the ground, and is resolved by the huge electric sparks that we call flashes of lightning. The thunder is only the noise of the spark.

Hail often comes from thunderclouds. Hailstones begin with the formation of ice crystals at high levels. They are carried up and down in the turbulent column of rising air, collecting alternate layers of white ice (due to rapid freezing) and of clear ice (collected at levels where freezing is slow).

(*b*) *Relief rain* occurs where moist air flows over high ground. Expansion under reduced pressure at high levels inevitably follows, leading to condensation and the formation of cloud. Relief rain is concentrated on the windward side of the relief barrier. On the lee side, by contrast, the winds are dry. The latent heat released during condensation on the windward side ensures that the descending air on the leeward is warm and able to evaporate moisture (Fig. 9). The effect is that of *rain-shadow* :

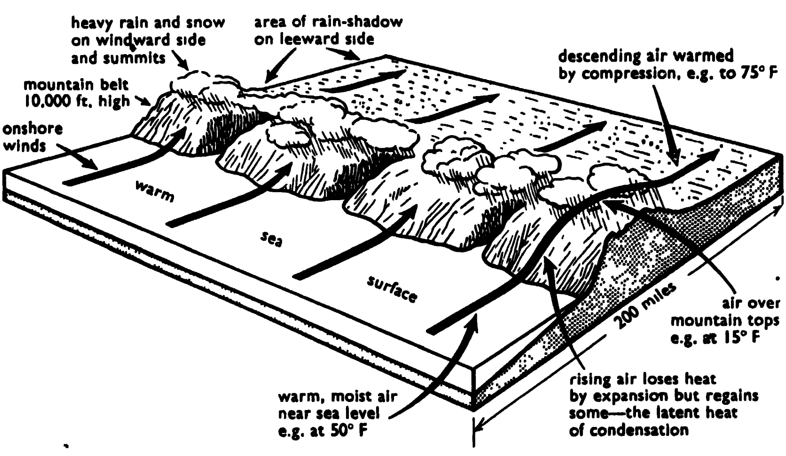


Fig. 9 ORIGIN OF CLOUD AND RAIN ON WINDWARD COASTS. Rain-shadow in lee of high ground.

notable areas of rain-shadow include the Canadian prairies, kept dry by the mountains of the Cordillera which stand in the path of the westerlies ; the Canterbury Plains of New Zealand, downwind of the Southern Alps ; and the Patagonian plains, with the Andes to the west of them. The eastern side of Great Britain, too, lies in the rain-shadow of the western uplands.

The warm, dry, descending wind is sometimes given a special name. In the Alps it is the *föhn*, in North America the *chinook*.

(*c*) *Cyclonic rain* is produced in the travelling low-pressure systems of the westerlies belts. In these lows, as has been mentioned, warm, moist, so-called tropical air rises over colder, denser, polar air. The effect resembles that of the flow of air over mountains, except that there is no descending current on the lee side. Expansion and cooling in the rising airstream again produce cloud and rain.

Cyclonic rain can obviously occur on low ground as well as on high. Lowlands in the path of travelling low-pressure systems can therefore have rainy climates, although they are always drier than the neighbouring mountain districts which receive relief rain as well.

Snow falls instead of rain when the air is cold enough. It is obviously typical of high altitudes and the winter season. At weather stations it is collected in a gauge and melted to give its equivalent in rainfall. This quantity is added to the amount of rain to give the total *precipitation*. The term 'precipitation' is better than 'rainfall' in descriptions of the climate of a place where snow falls every year.

2 Amounts of rain, and rainy seasons

A knowledge of the three kinds of rainfall helps to explain why some parts of the world are wetter than others, and why the rain falls mainly at certain seasons.

On the world map (Fig. 10) the equatorial belt stands out as very rainy. The fall is partly convectional, partly due to the ascent of air along the inter-tropical front. Extensions of the rainy belt occur where Trade Winds are onshore, and where

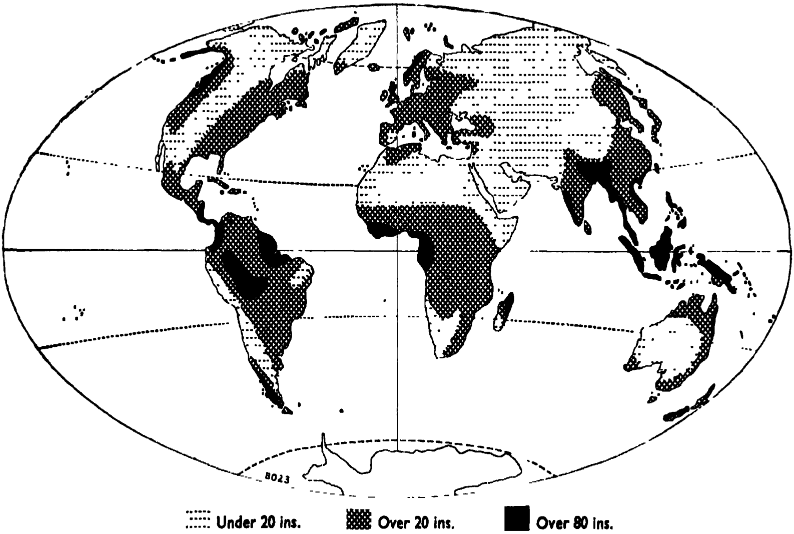


Fig. 10 DISTRIBUTION OF RAIN OVER THE LANDMASSES OF THE WORLD.

relief rain is heavy on high ground—in the area of the West Indies, in eastern Brazil, in Madagascar and on the coasts of Queensland. The heavy rainfall of much of southeastern Asia is a special case; it is due mainly to the summer inflow of monsoon winds, and as would be expected is particularly heavy in exposed mountain districts. In addition to relief rain there is much convectional rain here.

The sub-tropical belts are notably dry, being affected by the sinking air of the high-pressure systems. Their infrequent rainstorms are convectional. Between these and the equatorial regions come lands with rainfall mainly convectional and mainly in the summer, with moderate yearly totals.

The two belts of westerlies are both rainy. Cyclonic rain contributes largely to the annual total, together with heavy relief rain on exposed highlands. Rain falls at all seasons, but is least in summer. On the tropical side of the westerlies, and on the western sides of landmasses, summers are really dry. Rain comes in the winter months only. But towards the interiors of the landmasses the amount of rain decreases, and at the same time summer (or spring) becomes the rainy season and convection the chief cause of rain.

The distribution of rain through the year is called the *seasonal régime*. A little thought will show that it has great importance in human affairs. Water for generating power and for supplying industries and homes is needed all the year round, and the main consideration is to ensure a regular supply. But water for agriculture is needed in far greater quantities and must be available in the growing season. It is far simpler to supply homes and factories from reservoirs than to provide water for irrigating vast areas when the growing season is also the dry season.

3 Climatic characteristics

We can now summarise the items used in describing a particular climate. They include :

(i) amount of precipitation and its type
(ii) seasonal régime
(iii) mean temperatures for the warmest and coldest months
(iv) dominant winds, related to systems of pressure
(v) influence of the distribution of land and sea
(vi) influence of ocean currents
(vii) influence of high ground

On the basis of these, the following climatic types can be distinguished (Fig. 11), and are described in turn in the subsequent chapters :

Equatorial	Gulf
Sudan	Laurentian
Arid	Boreal
Semi-arid	Tundra
Monsoon (a group of climates)	Ice-cap
Mediterranean	Mountain and Plateau Climates
Northwest European	

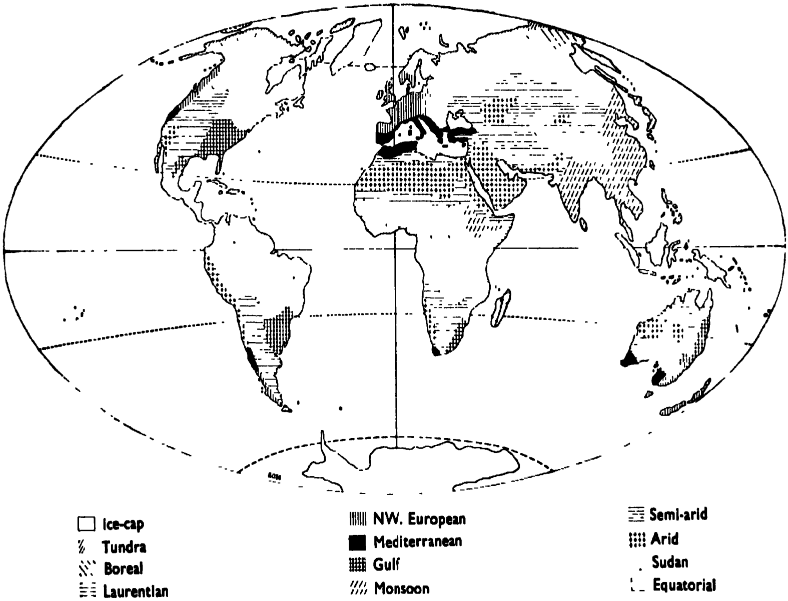


Fig. 11*a* DISTRIBUTION OF CLIMATIC TYPES.

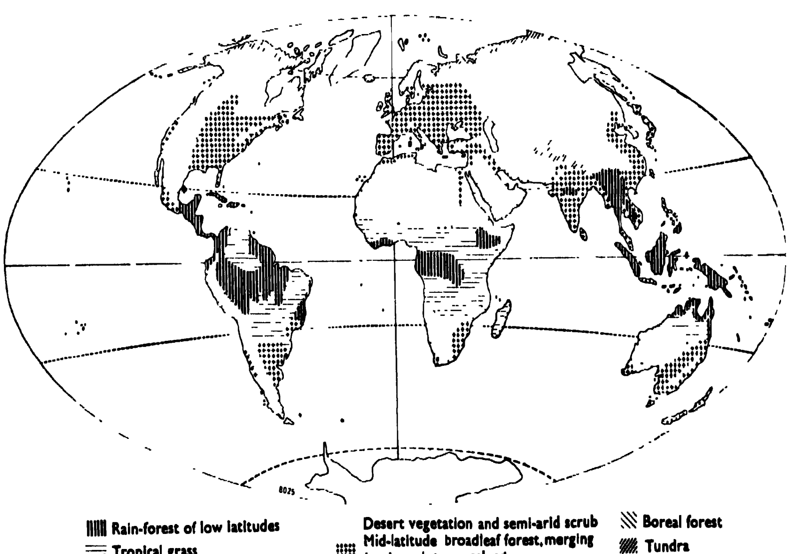


Fig. 11*b* VEGETATION AREAS. Distribution of types of wild vegetation : compare and contrast Fig. 11*a*.

Topics for discussion

1 Add to your record of weather the occurrence of frost, snow, and fog. If you can see any connection between frost and fog on the one hand, and calmness on the other, attempt to give an explanation of it.

2 In the lowland parts of the British Isles thunderstorms occur mainly in summer. Why is this ?

3 What effect, if any, does high ground have on the rainfall of your home area ?

4 Using records from a local rain-gauge or the data published for a nearby station in *British Rainfall*, plot graphs to show (*a*) the monthly rainfall during a single year ; (*b*) the average monthly rainfall over a period of years. Explain as fully as you can the differences between the two graphs.

5 Account for the fact that many of the large reservoirs of Britain, and all the hydro-electric stations, are found in the north and west.

6 Referring to the statistics published in a geographical textbook, select two stations, one with most of its rain in the summer half of the year and one with most in the winter. Account for the contrast between the two.

Chapter Five

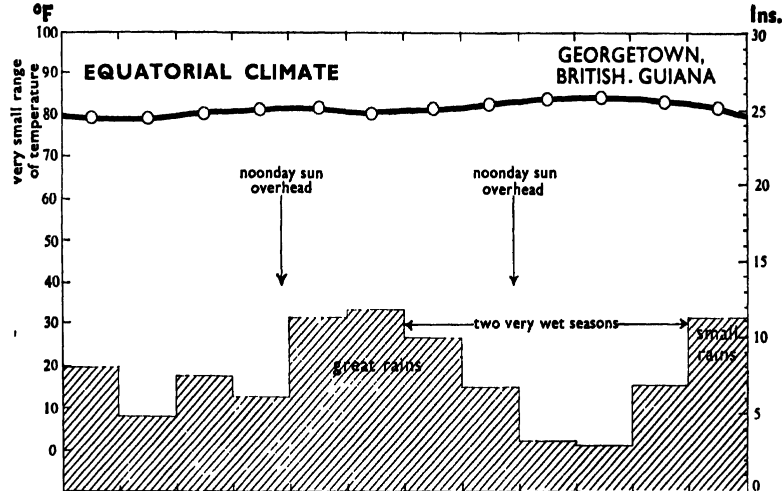
EQUATORIAL AND SUDAN TYPES OF CLIMATE

THE equatorial and Sudan types are the climates of the equatorial and tropical forest lands and of the tropical grasslands. Temperatures are high throughout the year. The mean annual temperature is 70° F or above, and no month has a mean temperature below 64° F. These climates can be said to have no winter. The arrangement of seasons depends on the distribution of rain through the year.

I Equatorial climate

This climatic type occurs in equatorial South America (except in the Andes), in parts of equatorial Africa, and in the lowlands of Malaya and the East Indies. A similar climate extends away from the Equator, where onshore Trade Winds bring heat and moisture from a warm ocean. These conditions obtain in windward coastlands of the West Indies and Central America, in eastern Brazil, eastern Madagascar, Natal, and northeastern Australia (Fig. 11*a*).

In the true equatorial climate heat and moisture are oppressive. Mean temperatures are high and uniform—about 80° F. There is little difference from season to season, for the noonday sun is always high in the sky.



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG	SEP.	OCT	NOV.	DEC.	Year
Temp.	79	79	80	81	81	80	81	82	83	83	82	81	81
Rain	7·9	4·6	7·2	6·0	11·1	11·7	9·9	6·5	3·1	2·9	6·7	11·1	88·7

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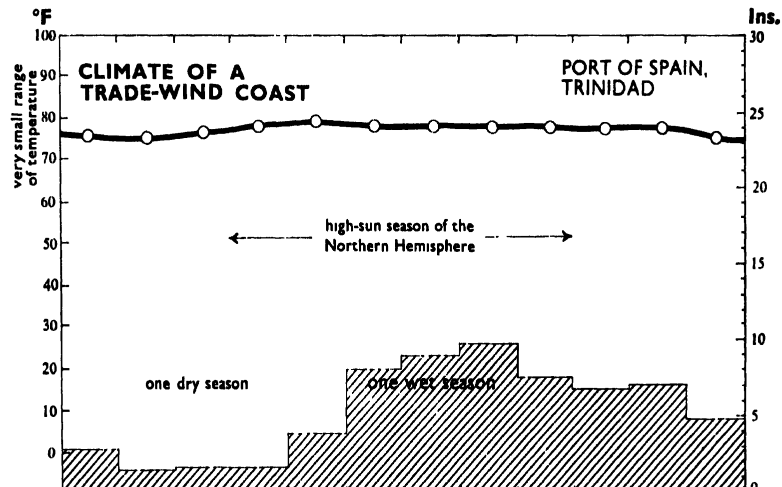
Fig. 12*a* GRAPH OF TEMPERATURE AND RAINFALL FOR GEORGETOWN, a station with an equatorial climate. Note that in all the climate graphs figures for temperature are in degrees Fahrenheit and for rainfall in inches. The yearly figure for temperature is the *mean*, while that for rainfall is the *total*.



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	75	75	76	78	79	78	78	78	78	78	78	76	77·3
Rain	2·7	1·5	1·8	1·8	3·6	7·9	8·8	9·6	7·4	6·6	7·0	4·7	63·4

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Fig. 12*b* GRAPH OF TEMPERATURE AND RAINFALL FOR PORT OF SPAIN, TRINIDAD, a station with a Trade-Wind coast climate.

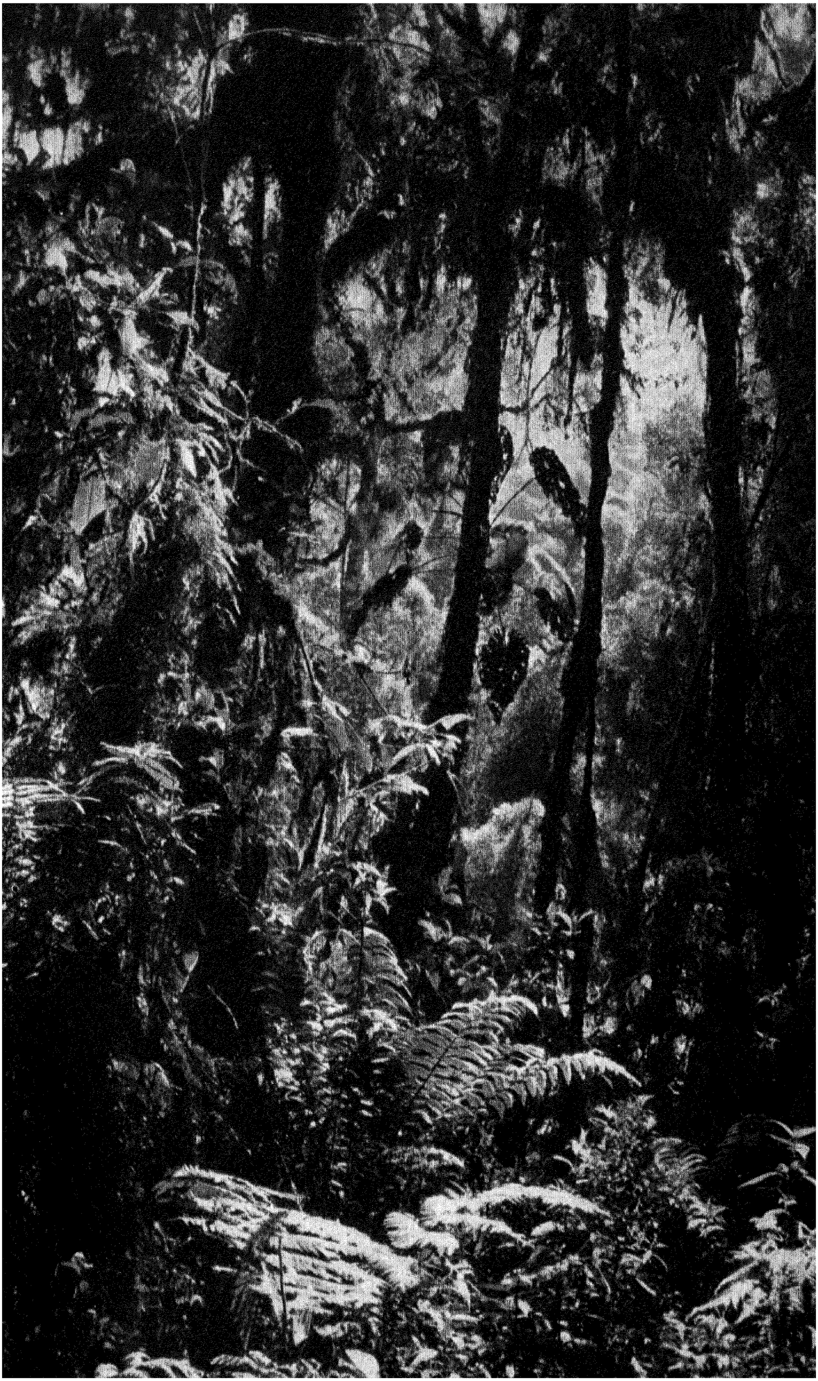
The equatorial rain-forests are the rainiest regions of the world. Vast areas receive more than 80 inches of rain a year. High temperatures mean rapid evaporation, and the air is always charged with moisture. In the calms of the Doldrums local differences of heating make columns of air rise, so that towering thunderclouds form and torrential rain falls. In addition, moisture is brought in from both sides by the Trade Winds, which interact along the inter-tropical front and give still more rain.

Equatorial rainfall is reliable as well as heavy. The greatest amounts fall in the seasons when the noonday sun is highest. In consequence many places have two very rainy periods each year, one wetter than the other, which are distinguished as the Great and Small Rains. Away from the Equator the two rainy seasons merge into one, which falls in the high-sun season of the hemisphere—compare Figs. 12*a* and 12*b*.

On occasions the coasts with onshore Trade Winds are afflicted by violent tropical storms—*hurricanes*—which resemble the travelling low-pressure systems of higher latitudes but are far more powerful. Hurricanes can move along the coast, devastating plantations and even towns. In some years the West Indies suffer severe hurricane damage.

Vegetation cover (Fig. 11*b*). As would be expected, where heavy rain and continually high temperatures occur together vigorous forests grow, composed of a bewildering mixture of trees and climbing plants. The trees are tall, their tops forming a canopy of leaves high above ground level and shutting out the sunlight (Pl. 2). Little light penetrates the gloom below and little underbrush can grow, but twining plants trail from tree to tree. Forest of this kind is called *selva*, its name in the Amazon basin. As there is little seasonal change of temperature and no shortage of water, plants can grow all the time and the selva is evergreen.

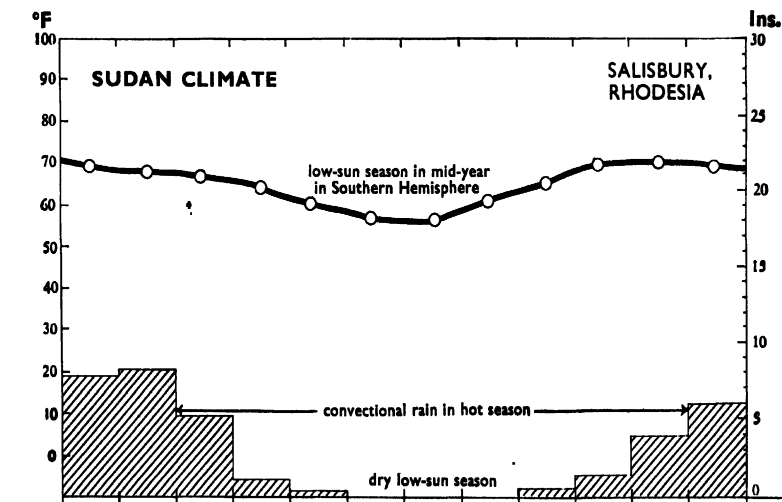
Plate 2 EQUATORIAL FOREST IN THE AMAZON BASIN. In the hot, moist air of this region trees grow vigorously, although the soil is poor in plant food. The tall trees have few branches below their crowns, but climbing and trailing plants are abundant.



Life in the selva. Wild animals, birds, reptiles, insects, and microbes flourish in the selva, but man has a hard time. The unpleasant climate does not suit people of the white nations, who have had little effect on the landscape—except where, as in Malaya and the East Indies, many plantations have been established. Tropical diseases are threats to health and to life itself. The most widespread is malaria, which kills thousands each year and weakens those who survive it. Travel is difficult. The forest is hard to clear and valley bottoms are swampy. The main routes are provided by the numerous rivers which are fed by the heavy rainfall.

In the selvas of the Amazon and Congo basins population is scanty. The dark-skinned pigmy peoples (negritos) live by food-gathering, hunting, and some cultivation. But crops are difficult to grow where vigorous forest soon reclaims the plots.

Soils. It is a mistake to suppose that the soils of the selva are naturally rich. They are, in fact, very poor. Although the rocks



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	69	68	67	65	60	57	56	61	65	69	70	69	65
Rain	7·5	8·0	5·0	0·8	0·2	–	–	–	0·5	1·2	3·9	6·0	33·1

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Fig. 13 GRAPH OF TEMPERATURE AND RAINFALL FOR SALISBURY, RHODESIA, a station with a Sudan climate.

rot deeply and quickly in the equatorial climate; and although there is a constant fall of dead vegetation, bacteria break down the humus and water carries away soluble matter. When a patch is cleared and planted the soil is exhausted in a few years, and a new plot must be made. In these conditions the selva can support but few people.

The Trade-Wind coasts, Malaya and the East Indies, are better placed. Their climates are less trying than that of the selva, and in all of them plantations have been set up. In Java, indeed, Dutch planters were able to settle permanently; but Java is a special case, with unusually productive soils and with an industrious native people—both rare in low latitudes.

2 Sudan climate

Wide belts of climate of the Sudan type adjoin the regions of equatorial and tropical rain-forest climate in Africa and South America. Sudan climate is also found in parts of Mexico, western Madagascar, and northern Australia (Fig. 11*a*).

The climate is dominated by the seasonal changes of pressure and winds. In the high-sun season the equatorial low pressure shifts towards the Pole, bringing rain from thunderstorms and from air rising at the inter-tropical front. Dry river-beds fill with water and vegetation springs into life. The weather is of the equatorial kind—hot, humid, and rainy. The amount of rain decreases away from the Equator, ranging between 20 and 40 inches a year, but it is not reliable and the amount varies from year to year. Temperatures during the hot season of the Sudan climate rise higher than they ever do in the rain-forest, for there are spells of burning sun when the sky is clear. The thermometer may go above 100° F in the shade, but tends to fall rapidly at night.

In the low-sun season of the hemisphere the equatorial low pressure shifts away, and regions of Sudan climate are invaded by the Trade Winds and the sub-tropical high pressures. Consequently there is little rain (Fig. 13). Temperatures fall, but the heat is still too great to justify the name 'winter'. In this

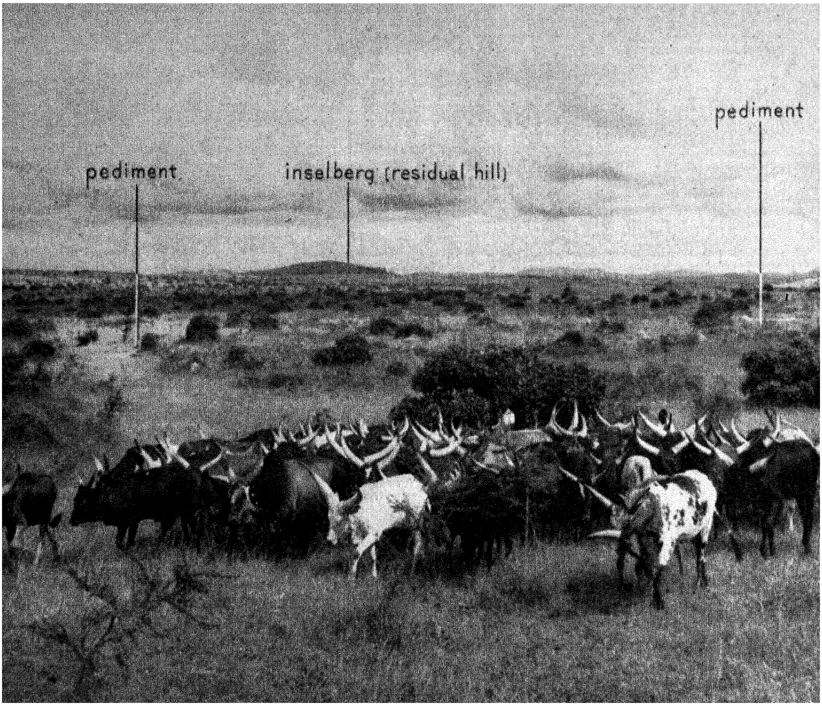


Plate 3 SAVANA GRASSLAND IN UGANDA, CENTRAL AFRICA, with a herd of long-horned Ankole cattle. The vegetation consists of grass and scattered bushes. The steep hills (inselbergs) and gently-sloping plateau surfaces (pediments) are explained in Chapter 19.

season rivers die away, vegetation is scorched, and annual plants die, while the surface of the ground is baked into a hard crust.

Vegetation cover (Fig. 11*b*). In the Sudan climate trees grow where there is enough water, especially along the banks of rivers. They are adapted to the seasonal drought, shedding their leaves at the end of the rains, and many are protected from animals by their thorns. Few grow to a large size.

By far the commonest form of vegetation, however, is tall tropical grass (Pl. 3). It dies down to the roots in the dry season and springs up again when the next rains begin. Tropical grassland is given a special name—savana. The savanas are the broad grassy plains and plateaux of tropical lands with a Sudan climate. But the climate alone does not explain the very wide range of tropical grassland. In some parts there is enough rain for forest, or at least for patchy woodland or scrub. Trees are kept down, not by drought but by fire.

On the grasslands of tropical Africa herdsmen have for centuries been setting fire to the parched grass in the dry season, in order to destroy the useless hard stalks and let the cattle get at the young shoots below. Natural fires are also frequent. Over-grazing has also helped to destroy trees. Whereas fire kills trees outright, the roots of grasses can survive it : the edge of the forest has thus been pressed back, and grass has occupied vast areas of land that once carried trees.

Using the tropical grasslands. The tropical grasslands support numerous herds of grazing animals as well as the flesh-eaters that prey on them. The animals of Africa include zebras, giraffes, lions, hyenas, and many kinds of wild cattle. Domestic cattle, however, are often of poor quality. They are frequently kept for prestige rather than for meat or milk, and numbers alone count.

As this is natural cattle country it is often claimed that meat could be produced on the savanas for export to the industrialised countries of western Europe, but a number of serious difficulties must be faced. The African grasslands are inhabited by native peoples, some herdsmen but others cultivators of maize and millet. Cotton, tobacco, and coffee are also grown—the last two mainly by European planters in the cooler highlands. It is not easy to convert an existing system, especially as the resources of the land are already strained in supporting the present population. Moreover, the African savanas lie on high plateaux, not easily reached from the coast, and the vast distances involved make external trade expensive. Cattle farming is seriously hampered by the tse-tse fly and other pests. Soil poverty is general.

The savanas of South America lie north and south of the Amazon selvas, being known respectively as the Llanos and the Campos. Each region stands on a plateau remote from the coast. Although cattle ranching has been practised for many years, particularly on the Llanos, it has rarely paid. A great deal of money has been lost, and the herds have declined during the last fifty years.

Soils. The Sudan climate is responsible for the poverty of the soil in the savanas. The rocks weather deeply, and during the rainy season the water soaks freely into the ground. It dissolves almost anything on which plants can live, including such essentials as lime, nitrates, potash, and phosphorus. Most of the dissolved material finds its way into the rivers and is carried away to the sea. In the dry season when evaporation is very strong, water rises to the surface of the ground and is dried up there. A rocky crust tends to form, consisting of a material called *laterite.* Laterite is composed largely of oxides of iron ; lateritic soils are among the poorest in the whole world, being so deficient in plant foods that in middle latitudes they would be barren.

In the African grasslands increasing soil poverty, frequent fires, and overgrazing have combined to destroy the natural plant cover. They have exposed the soil to the ravages of soil erosion. This in turn has diminished the amount of land that can be used for crops and cattle.

The future of the tropical grasslands. It seems inevitable that greater use must be made of the savanas in future years, for the world is threatened with a shortage of food. In northern Australia cattle ranching has begun on modern lines, but there also—as in the rest of the regions of Sudan climate—there has been trouble as a result of unreliable rainfall. The attempt to grow commercial crops in East Africa, with the aid of large machines, failed for a number of reasons. Unexpected drought occurred, and it was found that the problems of cultivation had not received adequate scientific study. It is clear that farming techniques suitable in mid-latitude countries are unsuitable in the tropical grasslands, and that much remains to be discovered about their natural conditions. Development in all parts of them will have to take account of natural hazards, and also of the inaccessible situations of the plateaux where most of the tropical grasslands are located. It is difficult to pay for new roads and new railways where the soils are poor, the people have no surplus wealth, and reserves of useful minerals are few.

Topics for discussion

1 Name the leading physical difficulties of life in the equatorial rain-forest. Choose any one equatorial region and say how these difficulties have been attacked.

2 Outline the equatorial environment as described in any recent account of travel and exploration.

3 Try to account for the myth that equatorial lands are rich and fertile.

4 Why is it that the equatorial lands are noted for their production of tree crops ?

5 In the foregoing text it is stated that laterite tends to form in regions of Sudan climate. In some localities, however, the product of weathering is not laterite but bauxite. Explain the meaning of the term *bauxite*, say what bauxite is used for, and locate on a world map the main producing areas.

6 In the British Isles a rainfall of 30 inches a year is ample for forest, but in tropical Africa it can support only grass and scrub. Account for this difference.

7 What common physical factors hamper the development of the economic life of the savana lands of the world ?

Chapter Six

ARID AND SEMI-ARID CLIMATES

1 Arid climates

Arid climates are those in which all the rain that falls can be evaporated. Indeed, the air is dry enough to absorb more water than actually falls. Large expanses of land with dry climates are therefore without permanent rivers. Many of the rivers that do exist flow only after one of the occasional rainstorms, and most of them soon dry up and disappear in the loose sand and stones. Even where rivers come down from rainy hills they may flow into a lake without an outlet, such as the Caspian, Aral, and Dead seas. Evaporation is so strong that these lakes never rise high enough to find an outlet to the ocean. Only the most powerful rivers, for instance the Nile and the Colorado, have enough water to enable them to cross an arid region and to reach the sea.

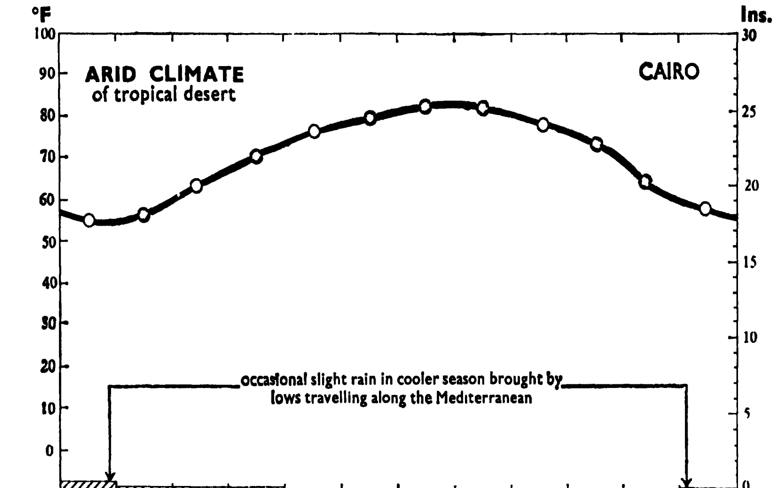
Distribution of arid climate. Arid climate can occur only where the air is especially dry, and where at least one season of the year is hot. If temperatures were always low there would be little evaporation, the soil would be kept moist and rivers could flow. But in arid regions the soil is parched almost all the time, and vegetation is therefore absent or scanty. Arid regions are found in two kinds of situation :

(i) On or near the Tropics. The tropical deserts are the best-known group
(ii) Outside tropical latitudes. In deserts outside the Tropics the influence of the oceans is shut out, and the deserts owe their dryness to distance from the sea, to very marked rainshadow, or to both factors combined

(i) *Tropical deserts.* This group comprises the Great American Desert, which straddles the border of Mexico and the U.S.A., the huge Sahara of northern Africa, the Middle Eastern deserts that extend into Persia, and the Thar Desert of India—all these lie in the northern hemisphere. Tropical deserts south of the Equator include the Atacama Desert of South America, the Kalahari in southern Africa, and the Australian Desert (Fig. 11*a*, Plates 30–3).

These regions are all dry because of the influence of the sub-tropical systems of high air pressure. In these systems air descends slowly from above, being compressed and warmed as it sinks. It is able to take up moisture from the ground and does not bring rain. At the surface of the ground winds blow outwards from the regions, as westerlies on the poleward side and as Trade Winds towards the Equator. Rain-bearing winds from the sea cannot enter and a dry climate prevails.

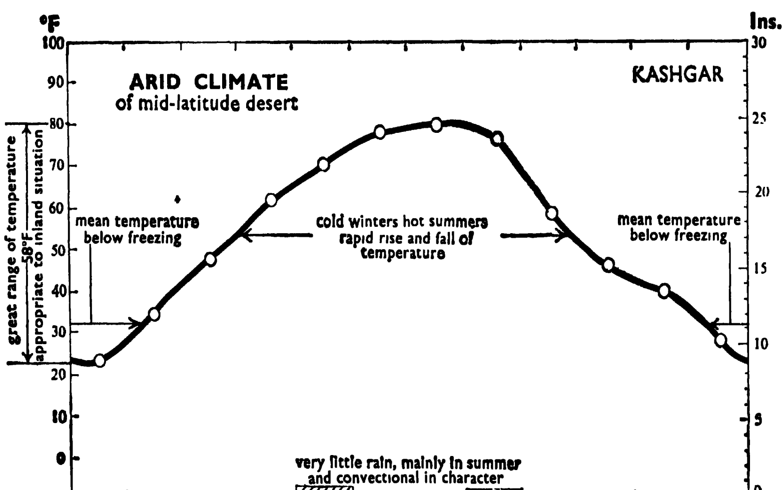
Although the desert lands become very hot in summer, and the overlying air may be forced to expand and rise, rain very seldom falls. Clouds may form, but even if they discharge rain it may well evaporate again before it reaches the ground. Any winds that may be drawn in from the sea are likely to be cool. We have noticed that on the western sides of the lands the winds come from cooler regions. They blow round the high-pressure systems over the oceans, and pass over cool ocean waters (Figs. 6, 7). Hence they are greatly warmed when they pass over the land, and instead of releasing moisture they are able to absorb it. The most impressive illustration of these conditions is given by the Thar Desert of India. A deep low-pressure system develops over the desert in the hot season. Winds are drawn



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG	SEP.	OCT.	NOV.	DEC	Year
Temp.	55	57	63	70	76	80	82	82	78	74	65	58	70
Rain	0·4	0·2	0·2	0·2	–	–	–	–	–	–	0·1	0·2	1·3

A140

Fig. 14*a* GRAPH OF TEMPERATURE AND RAINFALL FOR CAIRO, a station with an arid climate of tropical desert.



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	22	34	47	61	70	77	80	76	59	46	40	26	55
Rain	0·3	–	0·2	0·2	0·8	0·4	0·3	0·7	0·3	–	–	0·2	3·5

A141

Fig. 14*b* GRAPH OF TEMPERATURE AND RAINFALL FOR KASHGAR, a station with an arid climate of mid-latitude desert.

in from a *warm* ocean, and might be expected to give rain ; but by the time they reach the desert they have lost much of their moisture, and powerful heating in the desert region itself keeps the air there hot and dry (see Fig. 17*b*).

Note that the tropical deserts lie in the centre or western portions of the great landmasses, rather than on the east. The eastern sides are watered by rain from onshore Trade Winds, except in Africa. On the eastern side of tropical Africa the wind systems are disturbed by the Indian monsoon, while the coastlands of the Red Sea receive winds from Arabia which is itself arid.

(ii) *Deserts outside the Tropics.* The largest deserts outside the Tropics are found in inner Asia. Desert here occurs in enclosed basins deep in the interior of the continent. It extends widely eastward from the Caspian Sea, reappearing in the Tarim Basin with its mountainous rim, and in the Gobi Desert still farther to the east. These dry wastes lie many hundreds of miles from the sea, and are, moreover, affected by rain-shadow. By contrast, the Patagonian Desert of South America is dry merely because the high, continuous Andes collect the moisture of the westerlies as relief rain.

The main difference between the tropical deserts and those outside the Tropics is that the latter have cooler climates on the average, and that their winter temperatures can fall very low indeed—compare Figs. 14*a* and 14*b*. But since there is little cloud, the sun blazes down by day in all deserts and heat escapes freely at night. The characteristic large daily range of temperature is concealed by the average figures. The significant climatic fact of any desert remains the dryness which is the permanent problem of life there.

Desert scenery. The appearance of deserts varies far more than is usually thought (see Chapter 19). Some are sandy, some rocky, some gravelly ; few have no vegetation at all. In all the variety two things are clear : there is never a complete cover of wild plants, and the plants that do grow are highly specialised.

They are either adapted to withstand prolonged drought or else can grow, flower, and seed rapidly after one of the rare and irregular falls of rain. A rainstorm is always followed by an outburst of flowers. At other times seeds lie dormant; only the plants with fleshy stems, such as the cacti (Pl. 4), can store water for long periods, while certain others, including the date palm, are able to reach water deep underground by means of long roots.

These various adaptations are necessary on account both of the aridity and of the unreliable nature of the rain. Although it can be said that near the Tropics the climate is arid when the annual rain is less than 10 inches, averages mean little.

Water supply. Deserts have little except minerals to offer Man, unless water can be had. They have been throughout Man's history, and still remain, obstacles to travel. Their dryness, however, means that the soil—where there is any—suffers little loss by the dissolving action of water, and, although in places the soil is salt, elsewhere crops would grow well if water were supplied.

Any locality in a desert where water is available is called an *oasis.* There are four main kinds, all related to the special nature of desert regions.

(i) *Oases in valley bottoms.* Some oases lie in the bottoms of *wadis*—the steep-sided valleys with sandy floors that gash the mountains of many desert borders. For most of the time the wadis are dry, but they have been cut by the running water of short-lived streams. Much of the water evaporates, but some sinks into the sand and gravel. It is this portion that supplies the oases in wadis. Often a scattered line of trees and bushes runs along the bottom of the valley, and the underground supply of water may be used by man. In one of the Saharan wadis running southward from the Atlas mountains, date palms are cultivated for the exceptional distance of 750 miles. Usually the oases are scattered along the wadi and are isolated from one another by stretches of dry sand.

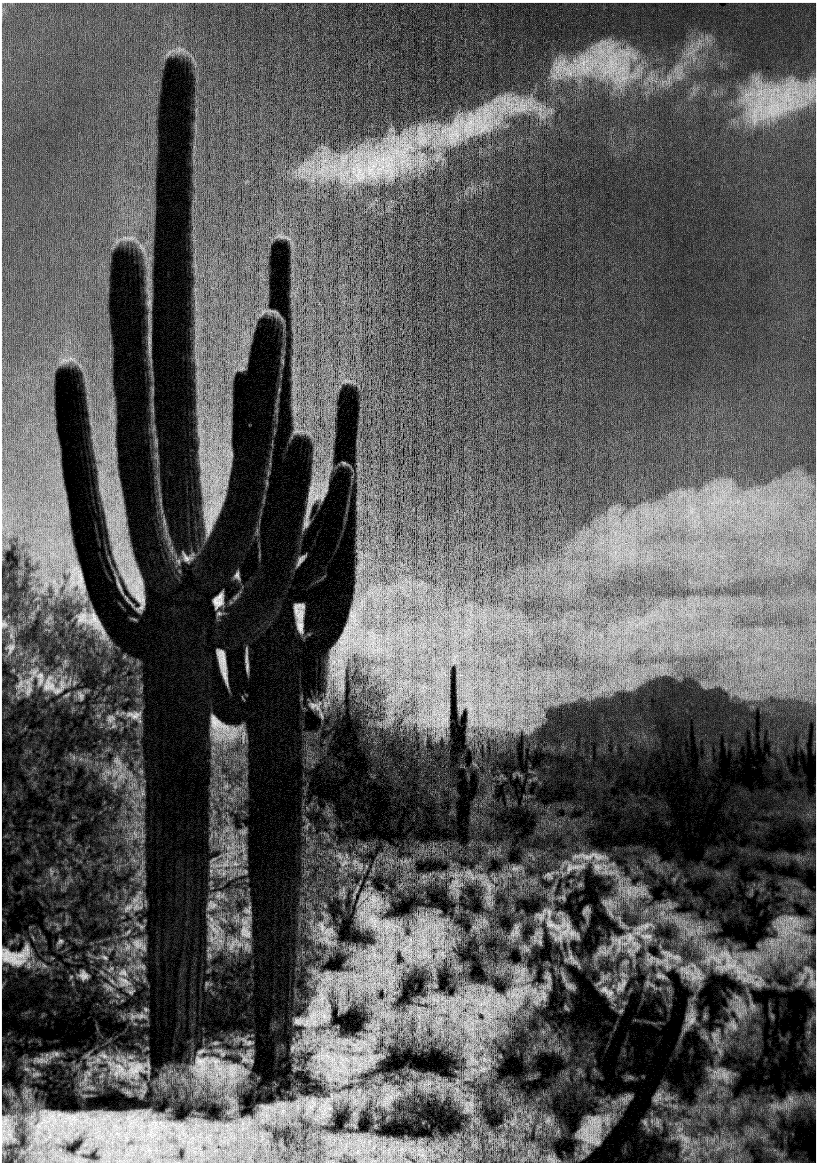


Plate 4 VEGETATION IN A TROPICAL DESERT. This picture shows part of the Sonora Desert, which stretches across the Mexican border into southwest Arizona. The desert is mainly low-lying, but its dry plains are interrupted by blocks of mountains. The vegetation includes many kinds of cactus, some growing to a very large size. Although some portions of this desert are quite rich in plants, the cover of vegetation is nowhere continuous.

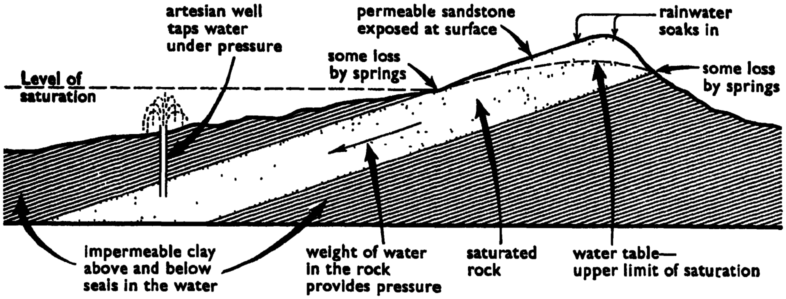


Fig. 15 ORIGIN OF ARTESIAN WATER.

(ii) *Oases on alluvial fans.* Where mountain streams enter desert basins they build fans of alluvium over the basin floor. If enough water comes down the rivers it can be tapped by wells or channels in the fan, and used for irrigation. These conditions are well illustrated along the mountain border of the Atacama Desert and in the Tarim Basin.

(iii) *Oases with artesian water.* A third kind of oasis depends on deeper supplies of water which are trapped in permeable rock between impermeable formations (Fig. 15). This is *artesian water* and the basin is an *artesian basin.* Some of the Saharan oases are fed by artesian supplies. Although in a number of them the water lies naturally near the surface, most of the supply today comes from deep borings. Australia makes great use of artesian water, having several artesian basins within the belt of semi-arid climate or on the actual desert borders. The supplies have been tapped for watering sheep.

(iv) *Perennial streams.* Finally, the well-watered land alongside the Nile can also be called an oasis. Without the Nile the land would be desert, but heavy rain on the Abyssinian highlands feeds a permanent stream, and a narrow strip of land on each side of the river can be irrigated and farmed. Under the influence of Europeans large storage dams have been built in the Nile valley; similar, and far larger, schemes of irrigation are found in the Thar Desert, where the waters of the Indus are used.

Where water is obtained in any of these ways the arid lands can be made to produce food. Without water they are either totally unproductive, or can support only grazing animals on huge areas of very poor pasture. Vegetation is so scanty at best that the herdsmen must be constantly on the move, and except at oases, mines, and oilfields the population is very sparse.

2 Semi-arid climate

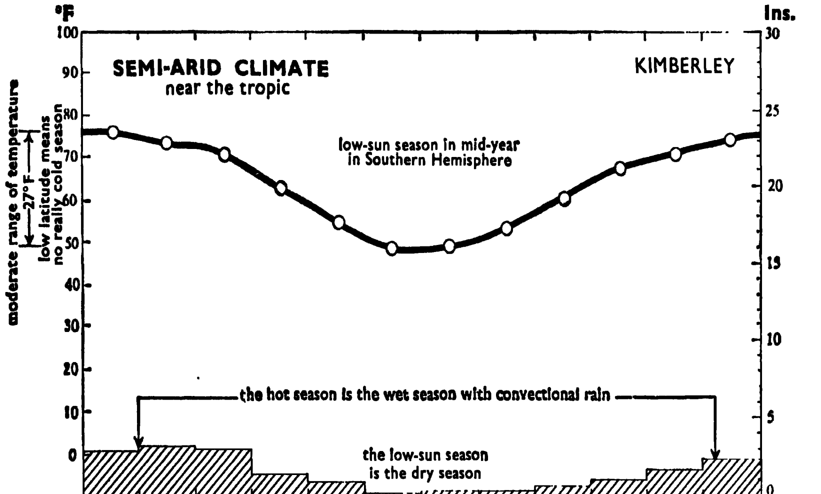
The deserts are truly arid. They are surrounded by belts of country where rainfall, although somewhat greater, is still low (Fig. 14). If we take the line of 10 inches of average yearly rain as the limit of tropical deserts, then the neighbouring lands with a semi-arid climate have an average of 10–20 inches a year. The semi-arid regions represent a transition from the deserts to the moister regions on either side.

(i) *Semi-arid regions in low latitudes.* The nature of the vegetation cover in semi-arid regions varies with the situation. Between the tropical deserts and the areas of Sudan climate there is usually poor grassland and scattered scrub, of the sort illustrated in Plate 34. Scrub also occurs on the poleward side of the deserts, where it marks the transition to the forest lands of middle latitudes—e.g. along the northern edge of the Sahara in Morocco. Here increasing rainfall towards the north coast brings in the distinctive forest of the Mediterranean lands.

Semi-arid areas in low latitudes have little more to offer than much of the desert. They too suffer from scanty vegetation, great heat by day, lack of water, and unreliable rainfall. The best that can be said for them is that they are not so dry as the truly arid parts—compare Figs. 16 and 14.

(ii) *Semi-arid regions of middle latitudes.* The physical environment is very different in middle latitudes, where vast grasslands are found in areas of semi-arid climate. As with the tropical savanas, these grasslands have been extended at the expense of forest by means of fire, and spread more widely than climatic influences alone would suggest. It would be more accurate to say that grass *used* to be very widespread, for much of it has been ploughed in the moister parts, and grain crops are grown.

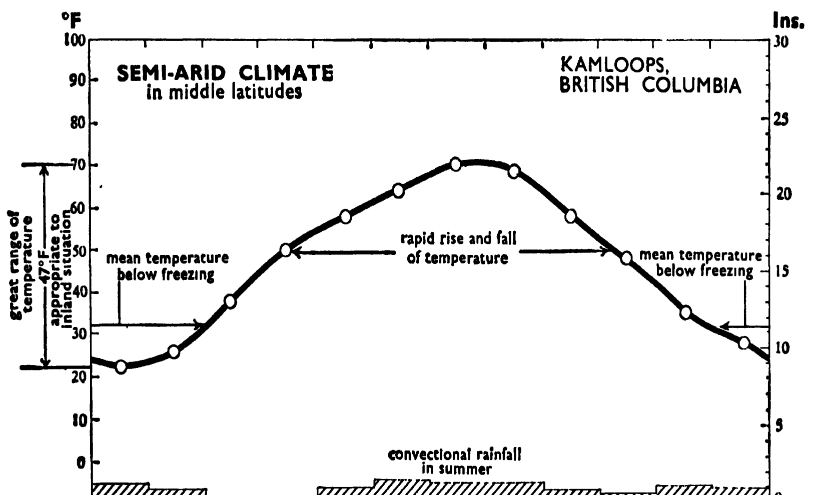
A general name for these grasslands of middle latitudes is *steppe*, or *grass steppe* to distinguish them from the patchy woodland of the wooded steppe. They include the North American



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	76	74	70	63	55	49	49	54	61	67	71	75	63 6
Rain	2·8	3·1	3·0	1·3	0·9	0·3	0·4	0·4	0·7	1·0	1·7	2·4	18

A142

Fig. 16*a* GRAPH OF TEMPERATURE AND RAINFALL FOR KIMBERLEY, a station with a semi-arid climate near the Tropic.



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	23	26	38	50	58	64	70	68	58	48	35	28	47
Rain	1·0	0·8	0·3	0·4	0·9	1·2	1·1	1·1	0·8	0·6	1·0	0·9	10·1

A143

Fig. 16*b* GRAPH OF TEMPERATURE AND RAINFALL FOR KAMLOOPS, BRITISH COLUMBIA, a station with a semi-arid climate in middle latitudes.

prairies, which lie partly in Canada and partly in the U.S.A., together with the broad belt of grazing land on the eastern flank of the Cordillera. A similar belt of country in similar latitudes lies in the U.S.S.R., north of the desert of the Caspian district and extending far eastward across Asia (Figs. 11*a*, 11*b*).

In these inland situations winters are cold and bring snow—note the average temperatures marked in Fig. 16*b*. The grass cannot grow either at this season, or in the height of summer when the sun is strong and evaporation at its greatest. Spring and early summer give convectional showers and the grass springs up then; there may also be renewed growth in the autumn. The annual range of temperature is great, for the grasslands feel the full effect of continental cooling in winter and of rapid heating in summer.

It is well known that the North American grasslands were the home of grazing animals, especially the bison, and of the nomadic Red Indians who hunted them. At the present day their drier western parts are used for cattle ranching (Pl. 5), but cultivation is steadily spreading with the aid of irrigation, or of special techniques of farming suited to the climate. The moister districts of the Russian grasslands have been cultivated for many centuries.

In the middle latitudes of the southern hemisphere occur three regions of semi-arid climate: the grasslands of Patagonia, the drier veldt of South Africa, and the Darling Downs of Australia (Fig. 11*a*). These all lie nearer to the Equator than do their counterparts in the northern hemisphere and in consequence have warmer winters.

Soils. The soils of the prairie and steppe lands benefit from the low rainfall and the annual growth of grass. There is not enough water to dissolve and carry away the natural plant foods, while the grass which dies every year has provided large amounts of humus. The soil is typically dark in colour. The first cultivators in North America found it highly suited to wheat farming. An added advantage is that the low relief of the prairie makes it possible to use large farm machines.

Plate 5 CATTLE ON THE GRASSLAND OF CANADA. Although large parts of the semi-arid regions of Canada are under the plough, their driest portions remain in grass, still strongly resembling the wild prairies of former times. The surviving grassland is ranching country where beef cattle are raised. Note the breed—these animals are descended from Hereford stock imported from Britain.

Topics for discussion

1 Choose one large area of desert and name the chief forms of wild animal life which occur there. Contrast these forms with those typical of the nearest region of savana.

2 Give an account of the great physical obstacles which separated the Greek and Roman civilisations from the contemporary civilisations of India and China. Illustrate your account by a map.

3 Artesian basins are not confined to desert regions—the London Basin contains artesian water. Draw a map and section to show the collection of artesian water in the London Basin, and explain where the rain falls which provides the artesian supply.

4 Many water-holes and some deep boreholes of desert regions yield salt water. Why is this ?

5 Draw a world map and mark on it the great grasslands of middle latitudes. Which parts of these are noted today as grazing areas ? Which parts are largely tilled, and what are their chief crops ?

6 Explain as fully as possible the very large annual range of temperature which is typical of the North American prairies.

7 What effects does this large range of temperature have on the life of the people ?

8 Large portions of the mid-latitude grasslands in North and South America were not settled until 1850 or later. Why was this ?

Chapter Seven

MONSOON CLIMATES

In southeastern Asia, from India to Japan, the climate is maritime for part of the year and continental for the remainder. The nature of the climatic year depends on seasonal changes of pressure over the land and on the associated changes in the winds.

In the cooler months the land surface grows cold. High pressure develops in the chilled air above it, and dry winds blow outwards towards the ocean. In summer the land is heated, the air above it is warmed and low-pressure systems form, and in consequence moist, rainy winds are drawn in. These seasonal winds are the *monsoons*, and climates dominated by them are *monsoon climates.* The flow of monsoons has already been mentioned; it is now time to consider the character of the climates which they dominate. Three low-pressure systems are involved. In the northern summer there is one over north-western India and another over east Asia, each with its own inflow of maritime air. In the southern summer low pressure develops over central Australia, drawing in winds across the East Indies. In all these areas, as will be shown, there are strong contrasts between the climates of different parts of the year, especially on coastlands which are exposed to the inflow of maritime air in summer.

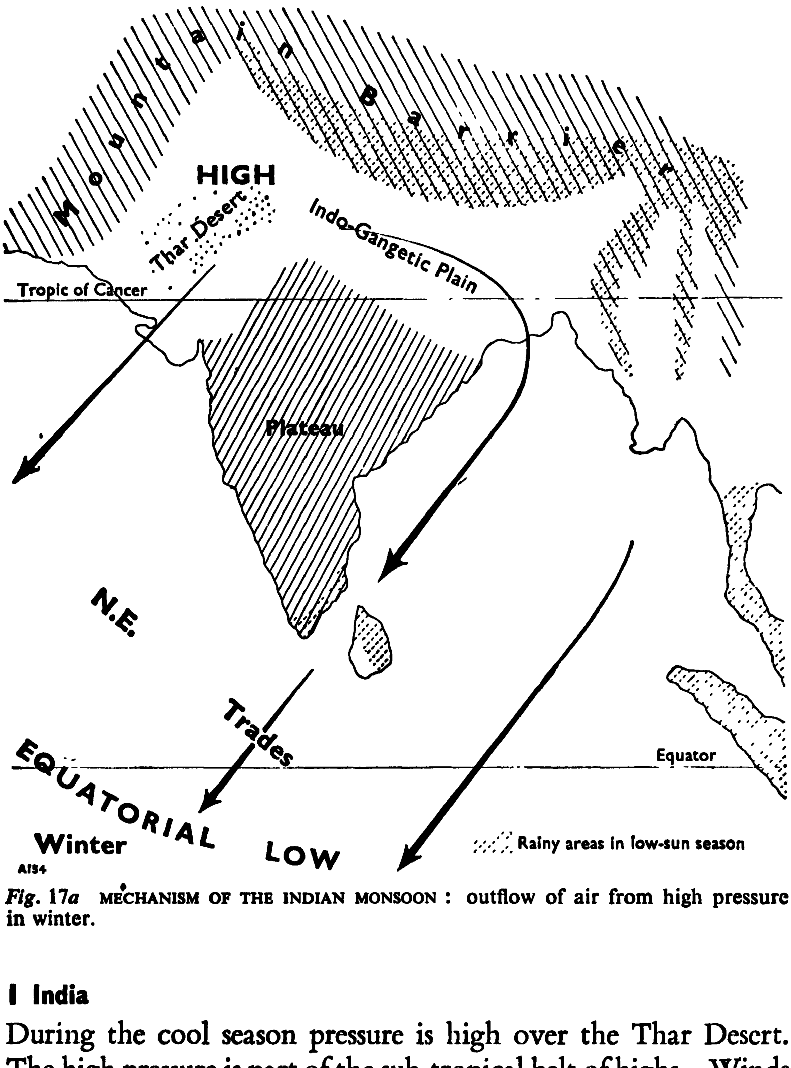


Fig. 17*a* MECHANISM OF THE INDIAN MONSOON : outflow of air from high pressure in winter.

1 India

During the cool season pressure is high over the Thar Desert. The high pressure is part of the sub-tropical belt of highs. Winds flow outwards from it. The northeast Trades blow directly over the Indian Ocean, while another airstream is channelled down the Ganges valley and feeds the Trade Winds over the Bay of Bengal (Fig. 17*a*). Over most of the sub-continent this season is dry.

When the overhead noonday sun shifts north of the Equator in the northern summer, air temperature rises and pressure falls, especially over the desert. The Trade Winds weaken and finally

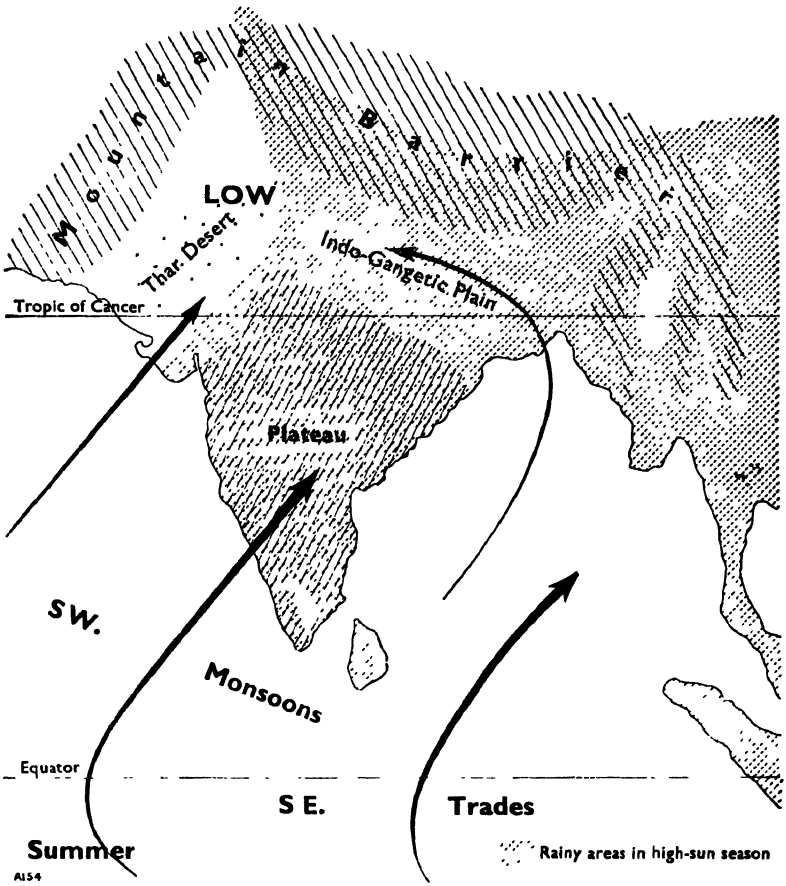
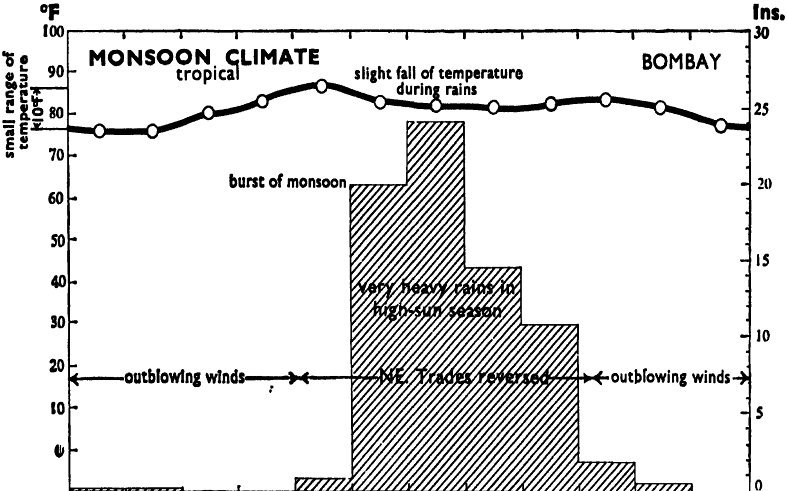


Fig. 17*b* MECHANISM OF THE INDIAN MONSOON : inflow of air to low pressure in summer.

cease. They are replaced by the indraught of the southwest monsoon. As the inflow becomes stronger relief rain commences on high ground. Finally air is drawn in from beyond the Equator. Heavy rain sets in, and the monsoon is said to burst (Fig. 18*a*). The wet season can be very wet indeed, particularly where mountains stand in the path of the winds. The wettest localities lie on the exposed western coast and in the lower Ganges valley, where the incoming air enters a huge funnel of lowland. Some places have 500 inches of rain a year ; others, in the rain-shadow of high ground, have less than 40 inches, while the centre of the desert has less than 10 (Fig. 17*b*).



	JAN.	FEB.	MAR.	APR.	MAY	JUN	JUL.	AUG.	SEP.	OCT.	NOV.	DEC	Year
Temp.	76	76	80	83	86	84	81	81	81	82	81	77	81
Rain	0·1	0·1	—	—	0·7	19·9	24·0	14·5	10·6	1·9	0·4	—	72·4

A144

Fig. 18*a* GRAPH OF TEMPERATURE AND RAINFALL FOR BOMBAY, a station with a monsoon climate (tropical).

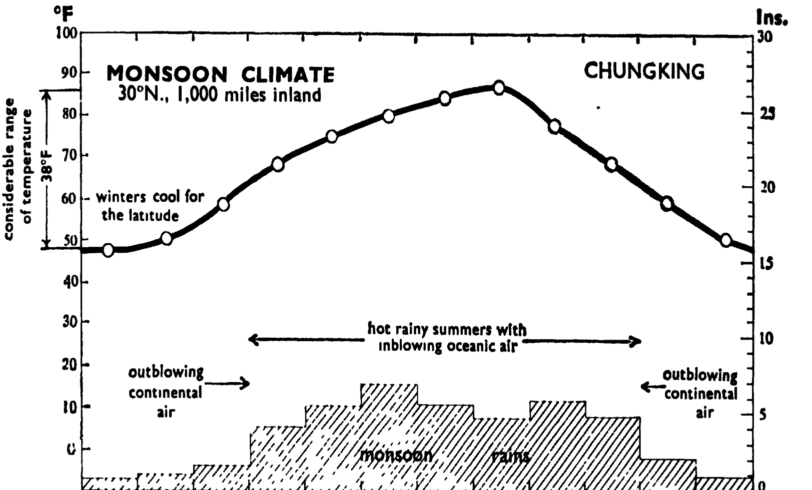
Vegetation cover. Spontaneous vegetation ranges from monsoon forest to scrub and savana, according to the rainfall, with true desert in the Thar. Monsoon forest, subjected to a marked dry season, is composed of deciduous trees. It is more open than the equatorial selva, so that undergrowth is luxuriant and the forest fully merits the name of jungle.

Irrigation. Agriculture depends on the monsoon rains or on the river floods that result from them. Unfortunately monsoon rain is unreliable and famine is a persistent danger. Most of the people in the Indian sub-continent live by farming, and much of the farming relies on irrigation. Four methods are practised.

(i) In the wettest regions floodwater can be taken from the swollen rivers, at times of high water, by *inundation canals.* The main crop in the submerged fields is swamp rice (Pl. 6).

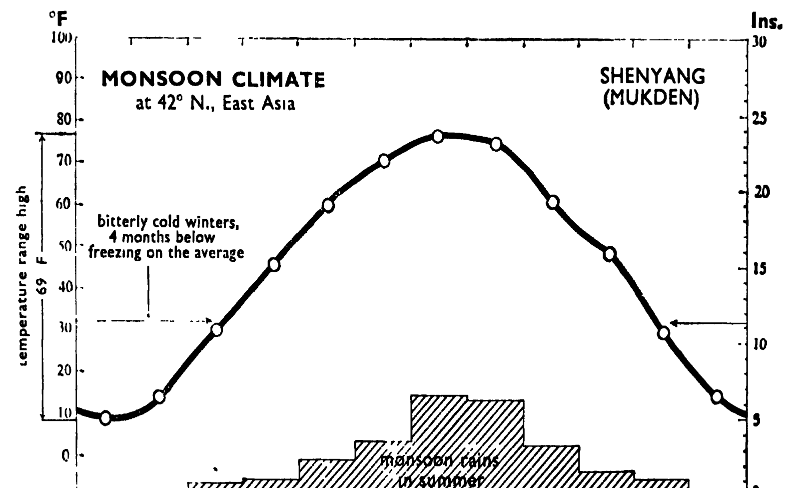
(ii) In the Ganges valley many *wells* are sunk into the alluvium.

(iii) Along the edges of the plateau, where deep narrow valleys



	JAN.	FEB.	MAR.	APR.	MAY	JUN	JUL	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	48	50	58	68	74	80	83	86	77	68	59	50	67
Rain	0·7	0·9	1·3	4·0	5·3	6·7	5·3	4·4	5·8	4·6	2·0	0·9	41·9

Fig. 18*b* GRAPH OF TEMPERATURE AND RAINFALL FOR CHUNGKING, a station with a monsoon climate at 30° N., 1,000 miles inland.



	JAN	FEB	MAR.	APR	MAY	JUN	JUL	AUG	SEP.	OCT	NOV.	DEC.	Year
Temp.	8	14	30	47	60	71	77	75	61	48	29	14	44
Rain	0·2	0·3	0·8	1·0	2·2	3·4	6·3	6·1	3·3	1·7	1·0	0·3	26·6

A146

Fig. 18*c* GRAPH OF TEMPERATURE AND RAINFALL FOR SHENYANG, a station with a monsoon climate at 42° N., East Asia.

Plate 6 CULTIVATION OF SWAMP RICE IN INDIA. The shoots of rice are being uprooted and tied in bundles, ready for transplanting in another field. Swamp rice is planted and grows in the water supplied by the heavy monsoon rains.

are cut into the high ground, dams of earth and brushwood impound reservoirs that are known as *tanks.*

(iv) In the Indus valley large modern dams of steel and concrete retain enough water to last throughout the dry season, and to feed *perennial canals.*

2 China and Japan

Monsoon climates occur along the whole eastern margin of Asia. Throughout this vast area the dry, continental climate of the cooler months contrasts with the moist, rainy summer. But within the total area of monsoon climates some kind of subdivision is necessary. Whereas southern China lies within the Tropics, Japan and the nearby mainland are in middle latitudes. In tropical China the winter season is never cold; at 45° N. the cold on the mainland is intense. There is also a decrease in the amount of rainfall with increasing distance from the Equator and from the ocean.

(i) *Southern and central China* (Fig. 18*b*). In the basins of the

Si-kiang and Yangtze-kiang rivers the summer climate is hot and wet enough for rice, which is the basic food crop. Mean July temperatures are above 80° F, and rainfall is generally more than 40 inches a year. As Fig. 18*b* shows, most rain comes in summer. Moisture and warmth are both increased by the influence of the warm Kuroshio Current. As on Trade-Wind coasts, hurricanes sometimes occur in summer.

In winter cold and dry winds flow out from the interior of Asia. This season is far cooler in China than it is in India, where high mountains shut out winds from the north. Mean January temperatures fall to 60° F on the Tropic, and to 40° F in the Yangtze delta. This means that the annual range is great.

Cultivation is as closely dependent on monsoon rain as it is in India. Alluvial districts are intensely farmed, and many hill-sides have been terraced for the growth of swamp rice. The monsoon forest has been cleared from large areas and replaced by farmland.

(ii) *Northern China and Manchuria* (Fig. 18*c*). In the basin of the Hwang-ho, mean January temperature is about 20° F, and the countryside is gripped by frost during the winter. July temperatures are high, however, reaching 80° F or thereabouts, so that rice can be grown. But since the growing season is shorter here than it is farther south, and rainfall amounts only to some 20 inches a year, wheat replaces rice as the main food crop.

(iii) *Japan*. The Japanese islands lie in a maritime situation. The Pacific (eastern) side has a rainy season in the summer, but the western side is rainiest in winter, when the winter monsoon picks up moisture from the Sea of Japan. In addition to monsoon rain, Japan may receive rain at any season from travelling low-pressure systems, which tend to follow the track of the Kuroshio Current. The difference in rainfall from season to season is therefore modified.

Northwards and westwards of China the monsoonal climates merge into other types. Inland lies the arid region of the Gobi Desert, out of reach of maritime influences, while to the north one enters the region of boreal climate, where the length of winter cold is the dominating factor (see Chapter 9).

3 Indo-China and the East Indies

These areas have already been described in Chapter 5, but they deserve a further mention here. Parts of Indo-China are drier than might be expected, for during the northern winter they are crossed by dry winds from the interior. This monsoonal outflow is supplied by the same seasonal high-pressure system that feeds the monsoon winds of China. It is directed towards the low pressure that lies over Australia in the southern summer.

The East Indies are affected by the same winds. The pattern of relief in these islands is much confused, so that climate varies greatly from place to place. However, it can be said that the northern sides of the islands tend to have their rainy season during the summer of the southern hemisphere, when air is flowing towards Australia, while the southern sides are wetter in the northern summer when they face the indraught into Asia. Throughout the East Indies there is one especially rainy season, when the monsoon rainfall is added to the convectional rain of the equatorial climate.

4 Monsoonal influences in other parts of the world

We shall observe in later chapters that monsoonal influences are felt in other climates than those of southeastern Asia. Warm maritime air is liable to be drawn over the land in summer, wherever extensive land exists in tropical or sub-tropical latitudes. But it is only in southeastern Asia that climates entirely dominated by the influence of monsoon winds, and by the rains brought by those winds, are developed over a very large area. Thus it is only the lands of southeast Asia that are known as the *monsoon lands*.

Topics for discussion

1 In some parts of the monsoon lands, as many as six crops of rice can be taken each year. In the British Isles only one grain crop a year is possible. Explain the contrast.

2 Why is rice so suitable a food crop for large portions of the monsoon lands ?

3 Explain why the tropical parts of the Americas are not subject to monsoon climates.

4 What are the hurricanes which sometimes devastate coastal districts within or near the Tropics ? Why are they so destructive ?

5 Generally speaking, the most densely-peopled parts of east and southeast Asia are those with the heaviest monsoon rains. What is the connection between heavy rainfall and dense population ?

6 Why are the great modern irrigation works of the monsoon lands found in the driest regions ?

7 What is the climatic explanation of the great famines which have occurred in India and China ?

Chapter Eight

CLIMATES OF TEMPERATE WESTERN MARGINS

THE Temperate Western Margins are the lands in middle latitudes on the western sides of the continents. Two kinds of climate are developed in them :

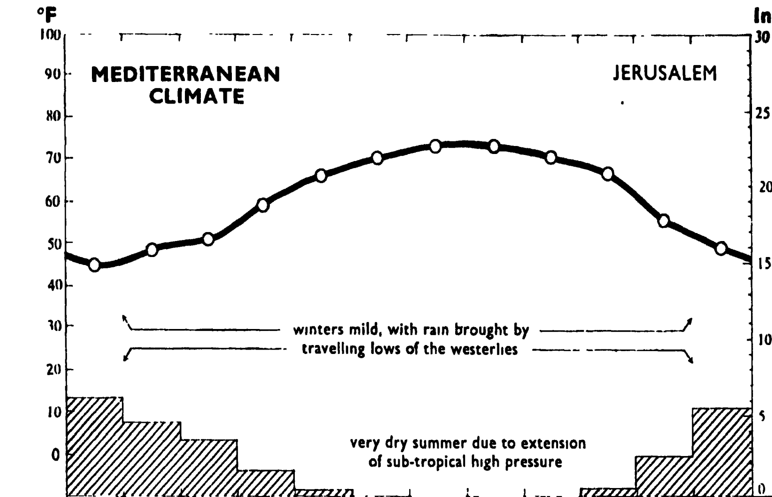
1 Mediterranean (warm temperate western margin)
2 Northwest European (cool temperate western margin)

Both types are influenced by the westerlies, but to different extents.

1 Mediterranean climate

This climatic type takes its name from the coastlands of the Mediterranean Sea. It is the precise opposite of the monsoonal climate that is developed in similar latitudes, i.e. 30° to 45° N., in eastern Asia. Instead of maritime conditions the Mediterranean climate has a continental summer. By contrast, the winters are subject to oceanic influences and are notably mild.

Seasonal régime. In summer the Mediterranean coastlands are affected by high pressure. The sub-tropical highs shift at this season towards the poles, and the sea surface, cooler than the surface of the surrounding land, tends to chill the air above it and to increase its pressure still further. At the same time the



	JAN	FEB	MAR	APR.	MAY	JUN	JUL	AUG	SEP.	OCT	NOV	DEC	Year
Temp.	44	48	51	59	66	70	73	73	71	67	56	49	61
Rain	6·2	4·6	3·5	1·5	0·3	–	–	–	–	0·4	2·5	5·7	24·7

A147

Fig. 19*a* GRAPH OF TEMPERATURE AND RAINFALL FOR JERUSALEM, a station with a Mediterranean climate.

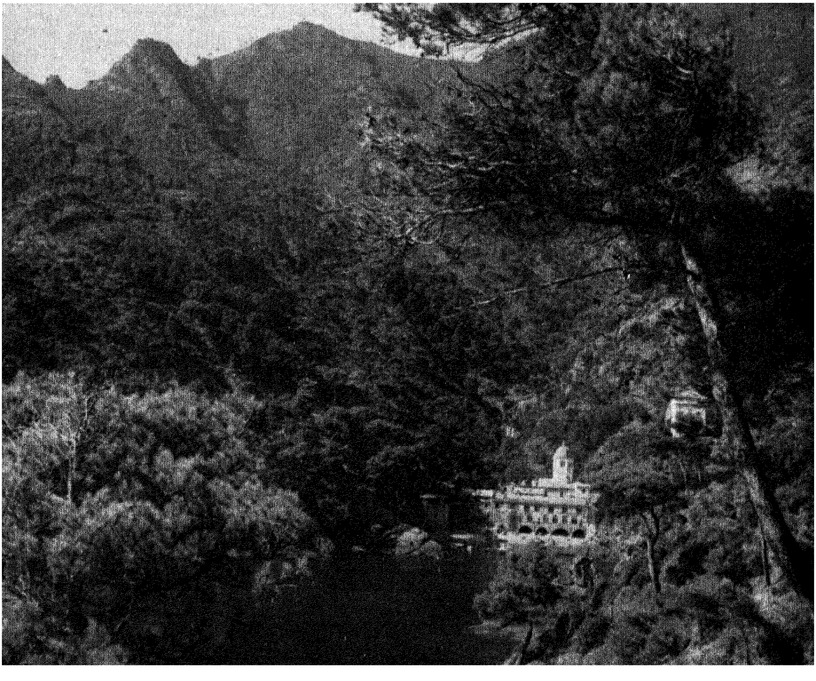
belt of westerlies has also shifted poleward. For all these reasons rain-bearing winds are unlikely to enter the Mediterranean region in summer. That season is typically one of heat and drought, with mean July temperatures above 80° F and long rainless spells.

In winter the sub-tropical high pressure has retreated towards the Equator. The slowly cooling sea is now warmer than the adjacent land, and air pressure above it is low. The belt of westerlies has shifted southwards, and travelling low-pressure systems pass along the Mediterranean. Winter, therefore, is the rainy season. Average winter temperatures are never low. The combined effects of the sea and of onshore winds keep the mean January figure between 40° and 50° F (Fig. 19*a*). Spring and autumn are seasons of transition.

Vegetation cover. The Mediterranean climate is warm enough to allow plants to grow all the year round, if there is enough water. The conditions do not suit grass, however, for the rain comes in the cool season when plants grow slowly. Trees, on the other hand, can withstand the seasonal drought if they are adapted to it—as by having long roots to reach water underground, or by having thick bark or waxy leaves to reduce losses by transpiration. The wild vegetation of the Mediterranean region is evergreen scrub forest, composed of drought-resistant trees. The forest is often patchy and the trees small—hence the name *scrub*—and the landscape has a tufted look. Evergreen oak is the commonest plant (Pl. 7), but there is also a wide range of aromatic plants and conifers as well as chestnuts and other hardwoods on higher and wetter ground.

Cultivation. The main crops include tree fruit and hard wheat. Farming is bound up with the régime of seasons. Wheat is sown in winter; although this is the wet season there is little prolonged rain to interrupt work on the land, and seed sown in December is ripe by early summer. Plants long adapted to the Mediterranean climate include the olive, vine, and fig. All

Plate 7 **MEDITERRANEAN FOREST ON THE ITALIAN RIVIERA. Conifers of modest size occur at low levels, but most of the slopes are covered with evergreen oak. The tufted, open appearance of the forest on the hillsides is typical of the Mediterranean region.**



have deep roots, grow well in this region, and are widely cultivated. Peaches, apricots, and the related almond are also common. But there are additional tree crops which have been introduced from regions of wet summers—oranges, lemons, limes, and grapefruit. These citrus natives of the monsoon lands need irrigation in the summer drought of the Mediterranean area, but the reliable summer sunshine guarantees ripe fruit.

Regions of Mediterranean climate outside Europe (Fig. 11*a*). Climate of similar régime, with warm or hot summers and mild winters, with winter rain and summer drought, is found in five localities outside the European Mediterranean—the Californian coast and the Great Valley, central Chile, the tip of South Africa, and southwestern and southeastern Australia. All these regions are subjected to high pressure and dry winds in summer, and to the mild oceanic westerlies in winter. They, too, have developed fruit-growing, notably California, which exports canned and sun-dried fruit in quantity and also produces wine.

Irrigation. In California, in central Chile, and along the northern shores of the European Mediterranean, the lowlands are backed by mountainous country. The ground here rises so high that thick snow falls during the winter and the highest summits are permanently snow-capped. The meltwater of spring and summer is much used for irrigation. In other areas water has to be taken from the large permanent rivers.

Mountain pastures. Although grassland is limited in the regions of Mediterranean climate, and is available only during the cooler part of the year, there is some food for grazing animals. Sheep and goats can feed on the scrub, where it degenerates towards the semi-arid lands and the plants become smaller. Again, parts of the Italian coast are marshy—sediment has filled lagoons and supports plants on which cattle can be grazed. But the greatest expanses of grazing land are located on the mountains.

Thousands of feet above sea-level, in climate too cold even for coniferous trees, grass comes in below the limit of permanent snow. In spring the winter snows melt and a rich cover of grassy plants flourishes in the clear air and the warm sun. Cattle and sheep are driven up from the low ground each spring, and are grazed on the mountain pastures until the next winter approaches. This seasonal movement of flocks and herds is called *transhumance*. It is commonest in the Mediterranean region of Europe, which has a long history of peasant farming and a dense population.

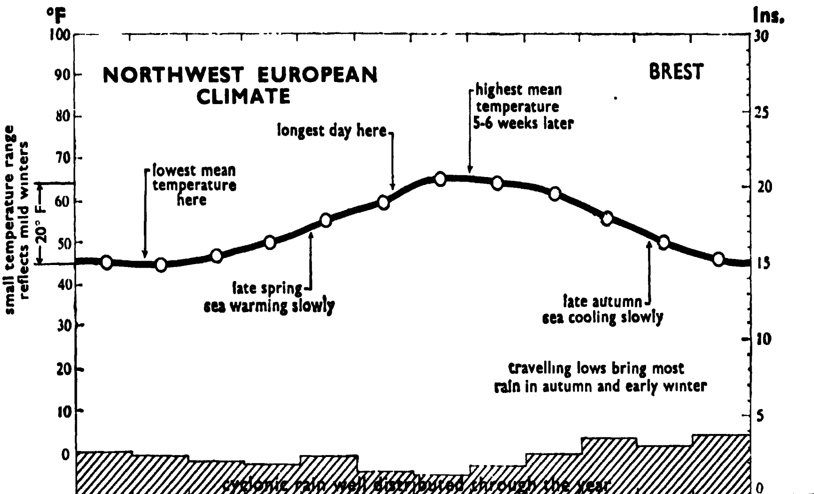
2 Northwest European climate

On the poleward side of the regions of Mediterranean climate lie areas where the westerlies dominate the climate throughout the year (Fig. 6). Summers are never really hot. The mean temperature never rises above 70° F, even in July. Winters are remarkably mild for the latitude, for much warmth is brought onshore from the oceans to the west. The annual range of temperature is therefore low. Rain occurs at all seasons and the weather is changeable. These are the characteristics of the Northwest European climate, the climate of cool temperate western margins (Fig. 19*b*).

Distribution. A glance at a relief map shows that this maritime climate can spread far inland across the plains of Europe, for the high ground of the western seaboard is broken. Elsewhere in the world continuous belts of mountains stand across the path of the dominant westerlies, with the result that climate of the Northwest European type is confined to parts of the coastlands. Such is the case in British Columbia and the adjacent states of the U.S.A., in southern Chile, and in New Zealand. Note that Tasmania is also included in the distribution of this climate.

Rainfall in all these areas is well distributed throughout the year. On the high ground there is heavy relief rain and snow. In summer thunderstorms occur over the plains. All areas at all seasons receive, in addition, the cyclonic rain brought by travelling low-pressure systems.

Travelling lows. These lows—also called cyclones or depressions—are responsible for the raininess of the Northwest European



	JAN.	FEB	MAR	APR.	MAY	JUN	JUL	AUG	SEP.	OCT.	NOV.	DEC	Year
Temp.	45	45	47	50	55	60	65	64	61	56	50	46	54
Rain	2·6	2·4	2·2	2·1	2·4	1·5	1·3	1·9	2·5	3·4	3·1	3·7	29·1

Fig. 19*b* GRAPH OF TEMPERATURE AND RAINFALL FOR BREST, a station with a Northwest European climate.

climate and for its changeable weather. They form on the polar front, where the westerlies interact with cold air from polar regions (see Chapter 3). A low begins as a bulge on the front, growing larger and moving eastwards across the ocean and over the land.

The westerlies bring oceanic air, mild and moist—*tropical air.* It rises in a travelling low over the heavier, colder, *polar air.* As in the rise of moist air over a relief barrier, the ascending air expands, cools, and condenses its moisture: cloud forms and rain falls. The appearance of a travelling low on a weather map is familiar nowadays from newspapers and from television broadcasts. The tropical air occupies the *warm sector* (Fig. 20), and rain is produced both in front of the warm sector and behind it. As the low passes over, taking perhaps one or two days, the weather changes rapidly. Its approach is heralded by thickening and descending cloud; then comes the rain associated with the *warm front,* the muggy, cloudy weather of the *warm sector,* and after that the sharp downpours along the *cold front.*

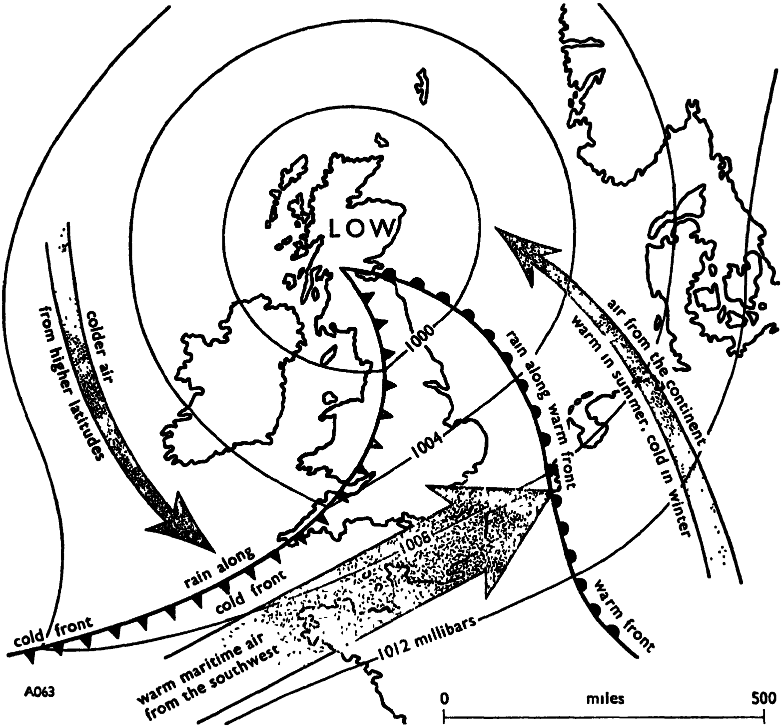


Fig. 20*a* A TRAVELLING LOW, showing import of different kinds of air.

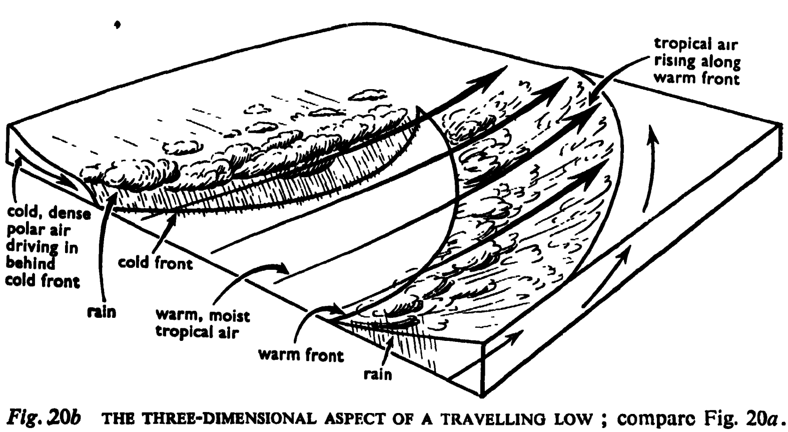


Fig. 20*b* THE THREE-DIMENSIONAL ASPECT OF A TRAVELLING LOW ; compare Fig. 20*a*.

The swift changes in weather as a low passes over are due to the contrasting kinds of air that it brings. In winter the forepart of a low may involve bitterly cold air from the interior of the frozen continent; as the warm sector passes over the thermometer rises quickly, while behind the cold front raw air may come in from over the northern Atlantic.

Vegetation cover. The rainy climate of the Northwest European type favours the growth of forest. In mild situations the familiar trees are deciduous hardwoods with broad leaves, such as the oak, ash, elm, and beech. But in the more rigorous conditions of high ground, greater nearness to the Pole, or poor soil, evergreen conifers replace the hardwoods. In very damp situations grow the mosses and sedges whose remains form peat, while much open moorland is covered by heather. Wild grasses are extensive in a single area—the Canterbury Plains of South Island, New Zealand, which lie in the rain-shadow of the Southern Alps.

It should be remembered that in the northern hemisphere this climatic type extends beyond 45° N. This means that winter nights are long and the growing season is short, and also that although the lowlands may be cultivable the highlands are liable to be bleak and barren.

Clearance of the forest. A very large part of the former forest cover of northwest Europe has been cleared, and the land used for farming. In Britain forest clearance has been going on for two thousand years, and much had already been done before the end of the Middle Ages. In other parts of the world with similar climate, settlement was more recent, and more of the forest survives.

Farming. Although so much woodland has been cleared in Britain and Europe, the climate has changed very little. In conjunction with soil, it sets a limit to the possibilities of farming. A wide range of crops is, in fact, possible—food grains (wheat, barley, oats, and rye), many root crops, and grass for pasture and hay. There are, naturally, differences between one area and

Plate 8 MIXED FARMING IN ENGLAND—a view along the Hog's Back, Surrey. Cultivated fields are interspersed with patches of woodland. A narrow strip of open land occurs on the top of the ridge, but apart from this nearly all the land visible is productive. Woods as well as fields are deliberately and carefully managed, and nothing remains that can truly be called wild vegetation.

another, even in a country as small as Britain. But it is fair to say that in Lowland Britain farming is of a mixed type, with livestock, grain crops, and roots on most farms. In a regional study of Britain it is important to make out strong contrasts between one region and another—for instance, between the climatically genial southwest and the more extreme region of East Anglia; even within the lowlands, significant differences occur between different regions. But for the present purpose, when we are considering a climatic type as a whole, we may conclude by noting that a view of farmed land (Pl. 8) is far more typical of northwest Europe than is a view of wild vegetation.

Topics for discussion

1 There are many resorts on the Mediterranean coastlands of Europe. Why are they winter, rather than summer, resorts? What special attractions do they offer to their visitors, and where do these visitors come from?

2 The country people of the Mediterranean lands of Europe eat little meat. Explain the relation of this circumstance to the nature of the Mediterranean climate.

3 Using the information given in Fig. 19*a*, calculate the percentage of the annual rainfall at Jerusalem which falls in the summer half-year. Make a similar calculation for Brest (Fig. 19*b*), and explain the contrast in the two régimes.

4 On a base-map with a scale of 6 inches to 1 mile, plot the use of land on a farm as near as possible to your home. Find out how much land is in grass, how much is tilled, and what kinds of animals are kept.

5 Where is the nearest woodland to your home? What kind of trees grow there? How can you tell that much of the woodland of the British Isles has been deliberately planted?

6 Where in the British Isles might you expect to find wild vegetation? What kinds of plants does it include?

7 The whole of the British Isles lies within the region of Northwest European climate, but contrasts exist between one station and another. What are the chief differences between the climate of Plymouth and that of Inverness, and how are they accounted for?

Chapter Nine

CLIMATES OF TEMPERATE EASTERN MARGINS

As on the western sides of continents so on the eastern side a distinct type of climate is found. On the east as on the west there are two subdivisions :

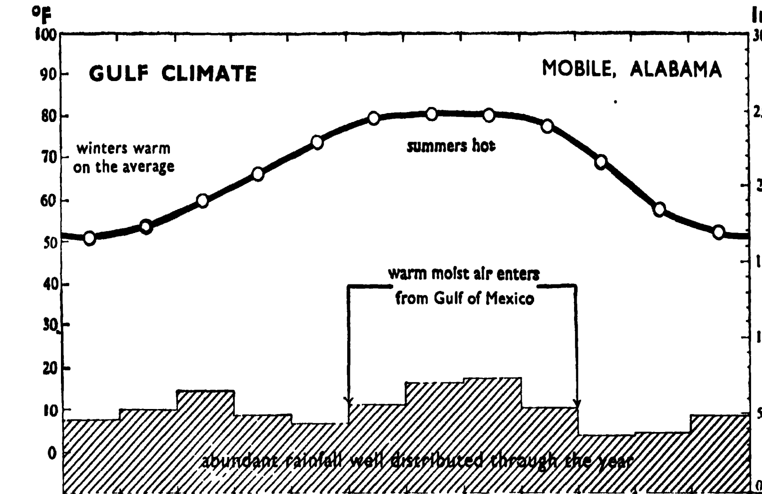
1 Gulf Climate (warm temperate eastern margin)
2 Laurentian Climate (cool temperate eastern margin)

Note that in this chapter the climates of eastern Asia are not discussed—they have already been reviewed under the heading of Monsoon Climates in Chapter 7.

I Gulf climate

(i) *The Gulf States.* A large area in the U.S.A., often called the Gulf States, gives its name to this climate (Fig. 11*a*). The summers are hot, with mean July temperatures about 80° F. There is a marked winter season with a January mean between 30° and 50° F, and the mean annual rainfall is 40 inches or more (Fig. 21*a*).

The considerable range of temperature reminds one of the Monsoon climates. In the Gulf climate it is true that oceanic influences dominate the weather of summer, while the lower temperatures of winter are due to seasonal cooling of the land. There are, however, no persistent seasonal winds of the monsoon



	JAN	FEB.	MAR	APR	MAY	JUN	JUL	AUG.	SEP	OCT	NOV.	DEC.	Year
Temp.	51	54	60	66	73	79	80	80	77	68	58	52	67
Rain	4·7	5·2	6·4	4·9	4·4	5·4	7·0	7·1	5·3	3·5	3·7	4·9	62·5

A149

Fig. 21*a* GRAPH OF TEMPERATURE AND RAINFALL FOR MOBILE, ALABAMA, a station with a Gulf climate.

kind, for the seasonal pressure systems are smaller and weaker in North America than in Asia. Besides this the Gulf States are influenced at all times of the year by travelling low-pressure systems. These cross the continent from west to east, or move inland off the waters of the Gulf Stream. Hence oceanic air may enter at any time, and the average figures for winter temperature conceal pronounced changes in the weather.

Winter rain is mainly cyclonic, that of summer largely convectional. Over the plains of the Mississippi basin heating is powerful during the summer months. Not only do thunderstorms form in the moist air that is drawn in from the warm Gulf, but sometimes tornadoes also occur. A tornado is a whirling storm, set off by intense local heating of the ground. It is small in extent, but its winds are extremely strong, so that it leaves a trail of destruction as it sweeps across the country. In coastal districts larger areas are damaged by hurricanes, which from time to time move north of the Tropic out of the Trade-Wind belt.

However, the scattered tornadoes and hurricanes of the hot

Plate 9 FARMLAND IN THE REGION OF GULF CLIMATF, U.S.A. The tall crop in the foreground is corn ; the fields in the middle distance are all under tillage, and the ridge in the background is under thick hardwood forest.

season, and the occasional waves of cold air in winter, are only incidental. In general this is a genial climate well suited to the growth of heavy-yielding crops. The southeastern states include the most productive farmland of North America.

Farming in the Gulf climate. Cotton and maize are the chief crops. Maize is grown through the climatic region. It is well favoured by the heat of summer, the humid air and frequent rain of the growing season, and by the sunshine during the period of ripening. Winter cold does not matter, so long as farmers can depend on four months without a killing frost. Cotton is more demanding. It needs two hundred days—nearly seven months—without frost, and is therefore confined to the southern part of the area, where the warming influence of air from the Gulf is felt most strongly and most often.

On the larger farms much of the work is done by machines, but in the early days of plantations only hand labour was to be had. Because the summer is so hot the white planters imported Negro slaves from Africa, and today there is a large coloured population in the Gulf States.

Vegetation cover. The region of Gulf climate was formerly forested in the wetter east and south, and grassed in the west, where the rainfall declines towards the interior. Nowadays most of the lowland is cultivated (Pl. 9). Forests survive mainly in the highlands. In the southern Appalachians, where most of the ground is steeply sloping, hardwood forest is extensive. Where the ground is sandy, the poor soil is largely under wild conifers, but lumbering is making inroads in the forest here. Finally, along the coast of the Gulf and in the interior of Florida widespread swamp forest with specialised trees, including the swamp cypress, covers the low-lying marshy ground.

(ii) *The Pampas.* Around the estuary of the Plate river in South America lies a region with a climate like that of the Gulf States (Fig. 11*a*). About half of it is grassland—the *pampas.*

The pampas lie closer to the Equator than do the prairie grasslands of North America, and have notably mild winters. The mean July temperature (for this is the southern hemisphere) is about 50° F. The annual rainfall is from 20 to 40 inches, and one might well expect the land to be wooded. It seems that here as in other great grasslands fire has been at work, killing trees and laying the ground open to grass. Much of this still remains unploughed, for the pampas carry large numbers of beef cattle. Tillage crops, mainly maize and wheat, are concentrated round the southern edges of the grazing district.

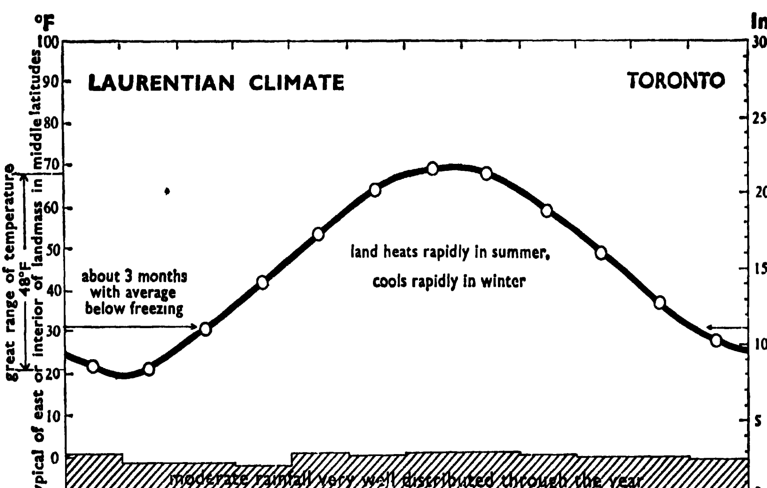
Rainfall increases towards the north, for seasonal heating of the land produces a monsoonal effect and the water offshore is warm. Inblowing winds are therefore warm and moist. Where the rainfall total is above 40 inches the grass is replaced by forest, much of it little touched by man.

(iii) *Eastern Australia.* On either side of latitude 30° S. in Australia there is a third development of climate of the Gulf type, on the narrow coastal lowland and the outer flanks of the mountains. This land was formerly wooded, but there has been much clearing, especially round the coastal towns. These settlements provide markets for farm produce and there is a concentration on dairying.

(iv) *The Natal Coastlands* have a situation and a climate similar to those of Eastern Australia, but a contrasted history of development. In Natal the main cash crops include tea and sugar grown on plantations with the aid of imported Indian workers.

2 Laurentian climate

The Laurentian climatic region lies farther north than the Gulf States (Fig. 11*a*), and has cooler summers. The mean July temperatures are between 60° and 70° F, resembling those of northwest Europe. But mean January temperatures are well below freezing (Fig. 21*b*). The large annual range shows that the Laurentian climate is far more extreme than the Northwest European. It results from the location of the Laurentian region on the eastern side of a landmass.



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	22	21	30	42	54	64	69	67	60	49	37	27	45
Rain	2·8	2·4	2·4	2·3	2·8	2·7	2·8	2·8	2·7	2·6	2·6	2·5	31·4

A150

Fig. 21*b* GRAPH OF TEMPERATURE AND RAINFALL FOR TORONTO, a station with a Laurentian climate.

Northwest Europe receives oceanic air at all seasons, in the form of onshore westerlies. The Laurentian region also lies within the belt of westerlies, but wind from the west in winter is of continental origin and bitterly cold. It keeps the temperature very low. Even if air comes in from the sea it is not always warm. Offshore flows the Labrador Current, between the coast and the warm waters of the Gulf Stream. The Labrador Current brings Arctic water far to the south, and winds passing over it are chilled.

Rainfall in the Laurentian climate is moderate in amount—a total of about 30 inches is common—and is well distributed through the year. Much of it is cyclonic, as would be expected in the belt of westerlies. Some of the moisture is brought in by winds off the Gulf Stream, and more is contributed by evaporation from the Great Lakes.

Eastern Europe. Climate similar to that of the Laurentian region is found in eastern Europe (Fig. 11*a*). This cannot properly be called an eastern margin climate, for the area lies deep within the continent. Nevertheless, it has mean temperatures of about 70° F in July and 10° F in January, a moderate rainfall and no dry season. For the sake of convenience, therefore, it may be called Laurentian. This region includes Poland and much of U.S.S.R. in Europe, and narrows away eastwards far into Asia. The extreme nature of the climate here is an effect of the great Eurasian landmass. Maritime influences become weaker and winter temperature falls as one goes eastward, and rainfall decreases in the same direction.

To the south lies the Caspian country, which experiences prolonged droughts; to the north is the boreal region, which in winter is exceedingly cold. Thus this second region of Laurentian climate is in every sense one of transition. It lies on the eastern margin not of a landmass, but of the broad region of Northwest European climate.

Vegetation cover and farming. The two regions of Laurentian climate were once covered by forest—hardwood trees on the lowlands and the more tolerant conifers on the colder uplands. In both areas there has been much clearance. Eastern Europe has been settled for centuries, proving more attractive than the dry country to the south or the softwood forest land to the north. In North America the St. Lawrence valley was one of the main gateways for immigrants from Europe. Its lowlands, together with the coastal areas of New England and the shores of the Great Lakes, are all thickly peopled. Wide expanses of forest have been cut down and replaced by mixed farmland and orchards.

Topics for discussion

1 Many of the early European settlers in the Gulf region of the U.S.A. were planters. How did the climate encourage the establishment of plantations, and what difficulties did it impose on the planters ?

2 Why is climate of the Gulf type more widely developed in North America than in any other part of the world ?

3 What are the main differences between climate of the Gulf type and Mediterranean climate ? How do you account for them ?

4 The Gulf climate does not occur in eastern Asia. Why is this ?

5 Find out the lengths of time during which the mouth of the St. Lawrence is closed by ice in winter. Why are its waters frozen every year, while the sea off southwestern Britain never freezes ? How far south does sea-ice come on the eastern side of the Atlantic ?

6 In the early days of settlement from Europe, the chief products of the Gulf region of the U.S.A. were plantation crops, whereas those of the Laurentian region were furs. What physical explanation can be given of the difference ? How does cash-cropping in the two regions differ today ?

Chapter Ten

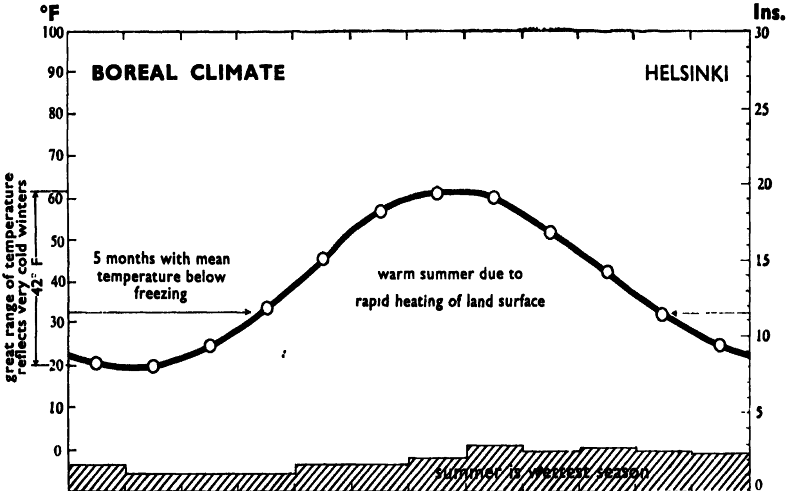
BOREAL, TUNDRA, AND ICE-CAP CLIMATES

1 Boreal climate

Two very large regions, one in North America and one in Eurasia, experience a climate with cool, short summers, and with cold winters when the mean temperature goes below zero. The air is seldom warm even in July. The two regions lie north of the polar front, and chill polar air overlies them during most of the year. As a consequence of the low temperatures the air cannot hold much water. Precipitation is never heavy, amounting to about 15 inches a year and coming partly as snow. Snow lies on the ground during the long winter months. These are the characteristics of boreal climate. Its extent is shown in Fig. 11*a* and the seasonal régime in Fig. 22*a*.

Vegetation cover in boreal regions. The commonest form of wild vegetation in regions of boreal climate is coniferous forest. As evaporation is slight the low precipitation is enough for trees, but they have to bear the bitter cold of winter. Most are evergreen softwoods, which can resist the severe climate and can live on the poor, acid soils which are widespread (Pl. 1).

Little progress has been made with farming. A number of experiments are in progress, but the short growing season is a serious handicap and is not offset by the length of summer



	JAN.	FEB.	MAR.	APR.	MAY	JUN	JUL.	AUG.	SEP.	OCT.	NOV.	DEC	Year
Temp.	21	20	25	34	46	57	62	60	52	42	32	25	40
Rain	1·8	1·4	1·4	1·4	1·8	1·8	2·2	2·9	2·5	2·6	2·5	2·4	24·7

Fig. 22*a* GRAPH OF TEMPERATURE AND RAINFALL FOR HELSINKI, a station with a boreal climate.

days. The forest itself, however, is a great source of wealth. The simplest form of exploitation is fur trapping. Although trapping has suffered from the competition of fur farms, some employment is provided by summer camps, fishing and shooting for sport in the North American forests. Timber, however, is the main commercial interest. The boreal forests provide a large fraction of the building timber used in the world today. Nearly all the familiar softwood, sold as *deal*, is produced here, besides enormous quantities of paper and paper pulp.

The boreal forests are noteworthy for their pure stands of timber. Dozens of square miles may be covered by a single kind of tree—fir, pine, larch, spruce, or silver birch, which is a hardwood. When the timber is worked the whole countryside is cut over. Lumbering is naturally concentrated in the most accessible areas. It started at the southern edge of the North American forests, next to the settled lands in areas of warmer climate and near to outlets for timber and pulp. There has been much waste through forest fires and neglect of replanting. At one time it looked as if all the readily accessible timber would be consumed, so that a severe shortage would occur, but in recent years management of the forests and of the lumbering industry has improved.

Nevertheless world consumption of softwood timber is still rising, and cutting goes deeper into the surviving forests. It is worth while, therefore, to note the reasons why the regions of boreal climate are not inexhaustible reserves of trees.

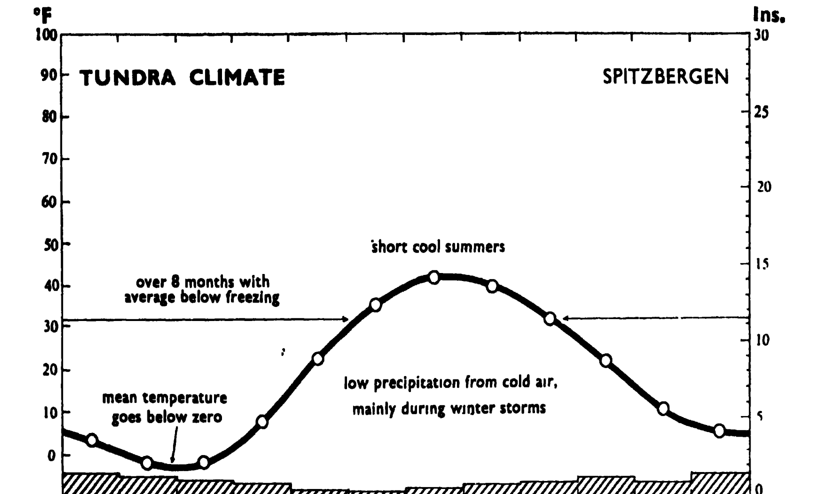
(i) *The effect of glaciation.* In the eastern half of Canada and around the northern Baltic most of the soil has been stripped away by ice-sheets. On bare rock nothing can grow but useless lichens, mosses, and heather. Innumerable hollows eroded by ice retain water and encourage the accumulation of peat. It is true that the lake basins provide natural reservoirs for hydro-electric schemes, and that in time peat may be used to generate power ; but lakes and bogs alike break the continuity of the forest and reduce the amount of timber.

(ii) *Spring floods in Siberia.* The boreal forests of the U.S.S.R. are known as the *taiga.* They are often referred to as vast untapped reserves of softwood, but little of the timber is easily accessible. Much of it is also of poor quality because the land on which it grows is swampy. The bottoms of the wide, shallow river valleys of Siberia are poorly drained, and are, moreover, subjected to flooding in spring. Since the rivers flow from south to north, their headwaters and middle reaches thaw in spring while their lower courses are still frozen. Every year, therefore, the channels are choked with masses of ice and volumes of flood-water. The low-lying valley floors are waterlogged in many places and incapable of producing high-grade timber.

2 Tundra climate

North of the boreal regions comes a belt of tundra (Figs. 11*a* and 22*b*). The climate here is too severe even for conifers. Summers are cool and very short, while the ground is permanently frozen at depth. Only the topsoil melts in summer.

Vegetation consists of lichens, mosses, annual grasses, and



	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	4	−2	−2	8	23	35	42	40	32	22	11	6	18
Rain	1·4	1·3	1·1	0·9	0·5	0·4	0·6	0·9	1·0	1·2	1·0	1·5	11·8

A152

Fig. 22*b* GRAPH OF TEMPERATURE AND RAINFALL FOR SPITZBERGEN, a station with a tundra climate.

sedges. Swamps occupy hollows; peat is very extensive indeed, for the air is usually cool and damp, and evaporation is always very slight. The general appearance of tundra lands is illustrated in Plate 18, which shows an area unused by man. Both in North America and in Eurasia, however, there are peoples who have adapted themselves to life in the tundra—Eskimo, Lapps, and Nentsi (Samoyed). They depend for their existence mainly on herbivorous animals—reindeer and caribou—and on fish and seals. The overbearing problems of living in the tundra are those of keeping warm and of securing a constant supply of food.

Although the tundra lands have nothing to offer farmers, they contain enough mineral wealth to attract the attention of industrial peoples. One of the major problems to be faced by miners is that of frozen ground. The foundations of buildings are never stable, unless they are cut in solid rock, for severe warping occurs as the ground beneath freezes and thaws with the changing seasons. Various devices have been tried, including the use of jacks underneath the frames of wooden buildings, but so far no way out of the difficulty has been found.

3 Ice-cap climate

The coldest climate of all is that of the ice-caps. We may say that, roughly speaking, the average temperature for the year is below freezing point. Precipitation always comes as snow. There is little melting, and the snow forms ice under its own weight. At the present day ice-caps cover most of the Antarctic continent and nearly all of Greenland, where recent soundings have proved thicknesses of 10,000 feet of ice.

Topics for discussion

1 Identify some of the chief fur-bearing animals of the boreal forests, and find out which of their furs are displayed in local shops or advertised in the local and national press.

2 What are the leading advantages of softwood timber for use in construction? Why is hardwood preferred, at least as a veneer, in making furniture?

3 Why is it easier to import softwood timber into Britain from Canada than from the northwestern U.S.S.R.?

4 What are the main physical difficulties of life in the tundra regions? How are these difficulties met in the exploitation of the mineral resources of these regions?

5 What is the maximum angular height above the horizon of the noonday sun on the Arctic Circle? Assuming that the earth's atmosphere is 200 miles thick, calculate the least distance that the sun's rays must pass through the atmosphere before reaching the ground at the Arctic Circle. Make similar calculations for the Equator and for one of the Tropics, and compare the several sets of results.

6 From the accounts of recent exploration, find out as much as you can of physical conditions on an ice-cap.

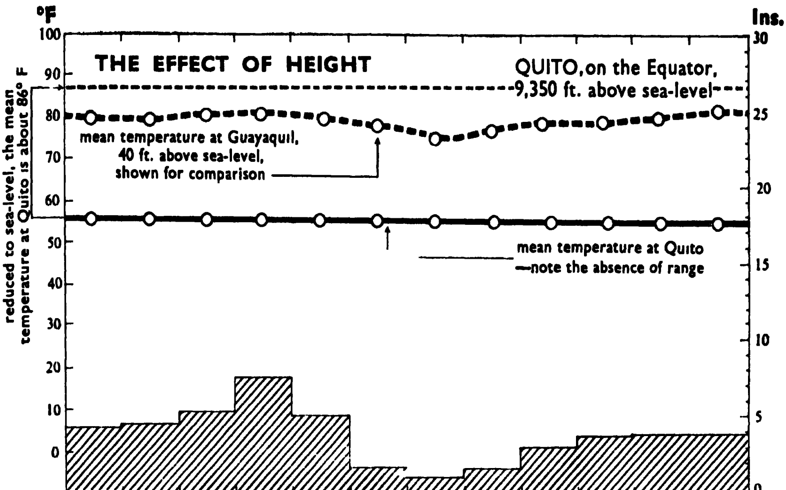
Chapter Eleven

MOUNTAIN AND PLATEAU CLIMATES

THE effect of relief on climate has already been mentioned. Relief as a climatic control was discussed in Chapter 2, and on several occasions belts of high ground have been seen to act as climatic divides. We have also observed that relief rain is likely to be heavy where the land stands high above sea-level. There is, however, still more to be said about the climates of high altitudes. The typically low air temperatures are not the only element that must be taken into account. A few examples will serve to make the matter clear.

1 The high Andes near the Equator

Consider, to begin with, the equatorial Andes. The climate of the town of Quito, lying almost on the Equator but at 9,350 feet above sea-level, is a frequently quoted example. The actual mean temperature here is 55° F, with a scarcely perceptible variation through the year (Fig. 23). The range is even smaller than would be expected from the latitude, while the low average figure reflects the influence of height. The climate here, however, is nothing like those of higher latitudes where a similar mean annual temperature is recorded. The differences include a noonday sun which is always high in the sky, the negligible



	JAN.	FEB.	MAR.	APR.	MAY	JUN	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Year
Temp.	55	55	55	55	55	55	55	55	55	55	55	55	55
Rain	4·2	4·3	5·2	7·4	5·0	1·5	0 9	1·5	3·0	3·7	3·8	3·8	44 3

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Fig. 23 GRAPH OF TEMPERATURE AND RAINFALL FOR QUITO, showing the effect of height.

range from season to season, and a great contrast between day and night temperatures. The very great daily range is also due to the height. During the day the sun's rays strike powerfully through the rarefied mountain air, and temperatures in the sun are much higher than those in the shade. This, indeed, is a common feature of mountain climates, both in low and in middle latitudes. By night heat escapes readily and the temperature rapidly descends.

2 The mountain border of Mexico

The eastern coastlands of Mexico, on the western side of the Gulf, are hot and rainy at low levels. The latitude is low and the Trade Winds bring in heat and moisture from the warm sea. But since the mountains behind the low coastal belt rise to heights of more than 15,000 feet there is bound to be a change of climate, and of wild vegetation and farm crops, with height.

(i) *Tierra caliente.* The lowest belt, from sea-level to about 2,000 feet, is the *tierra caliente*—the hot land. Wild vegetation consists of rain-forest; crops include cane sugar and rice.

(ii) *Tierra templada.* This is the temperate land, lying between 2,000 and 6,000 feet above the sea. The forest here is more open than in the tierra caliente, and includes many oaks at the higher levels. Clearing is easier than in the rain-forest and the climate is less oppressive than at lower levels. Leading crops are maize, tobacco, and coffee.

(iii) *Tierra fria.* Above 5,000 feet comes the *tierra fria*—the cold land. Few people live here, and night temperatures are too low for any but hardy crops. Coniferous trees appear at about 10,000 feet, and the upper parts of the forest are composed of fir and pine. Still higher than the forest there is much mountain pasture, between the upper limit of trees and the lower limit of snow, where cattle and sheep are kept on the open grassy plateaux and mountain shoulders. Above 15,000 feet the land is snow-covered the whole year round.

3 The Alps

This mountain region, lying in the heart of Europe, is the best known of all. It is notable for its clear air and powerful sun. The mountains rise above the lower levels of the atmosphere, where most of the dust and water vapour are concentrated, and the air is therefore much cleaner in the Alps than over plains and in industrial cities. The summer sun rises higher in the Alps than it does farther north, and although shade temperatures are low because of the height, the sunshine is warm. It is not surprising that the Alps should be called Europe's playground, for they have magnificent scenery as well as a special climate. The growth of health resorts, holiday centres, and the tourist industry have been deliberately encouraged, especially in Switzerland.

Aspect in the Alps. Not everyone in the Alps lives by the tourist trade, however, There is a considerable population of farmers. The distribution of farming settlements at the higher levels is closely related to the aspect of the settled sites.

Many of the Alpine valleys run roughly from east to west,

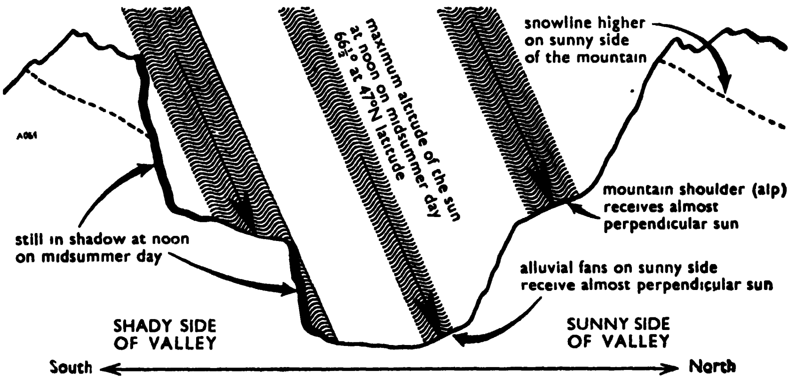


Fig. 24 THE INFLUENCE OF ASPECT IN AN ALPINE VALLEY.

so that one side faces south and one north. The south-facing side has the more sunshine, and farms are scattered along it wherever there is soil. The north-facing side, by contrast, is usually heavily wooded, being often in shadow and never receiving the perpendicular rays of the sun (Fig. 24).

4 The highlands of western Britain

The highlands of Britain are much lower than the Alps. Ben Nevis, the highest point of all, is only 4,406 feet high ; Helvellyn, in the Lake District, a little over 3,000 feet ; and Snowdon, in North Wales, just below 3,000. In the Alps settlement goes as high as 17,000 feet above sea-level, but even in North Wales the climate is too bleak for cultivation above 500 feet, while in western Scotland crops are confined to the very lowest levels.

There are three factors at work :

(i) Britain lies farther north than the Alps, and the sun is always less powerful

(ii) the British highlands stand close to the sea ; the onshore westerlies bring in cloud and rain, reducing the amount of sunshine

(iii) the deep Alpine valleys give shelter from the winds, whereas the open plateau tops of western Britain are fully exposed to cyclonic storms

We find, therefore, that ploughland is restricted to the valley bottoms and the lowest slopes of the hills.

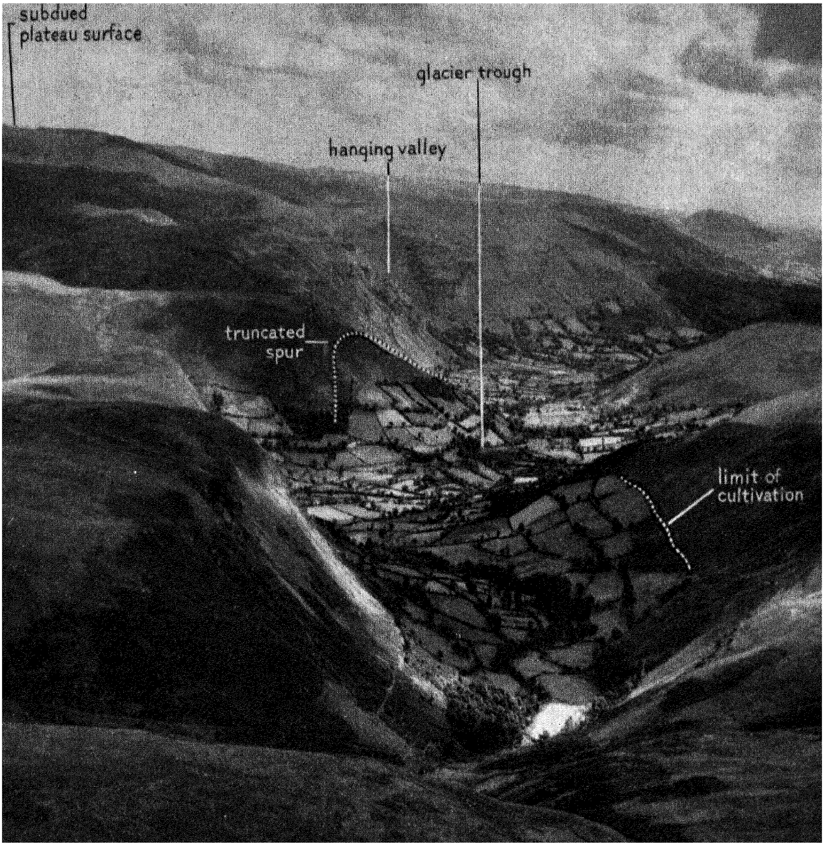


Plate 10 THE LLANGYNOG VALLEY, a glacier trough on the north Welsh Border. Note the cultivated land on the valley floor and the lower slopes of the valley sides, where soil of some depth is developed on boulder-clay. The upper valley sides are too steep for cultivation and the plateau top is too bleak. Glacial features are labelled for reference in Chapter 18.

The summits are often covered with peat and heather and are used only for sheep pasture (Pl. 10).

5 Summary

The effects of high ground on climate may now be summarised :

(i) mountains in the path of moisture-bearing winds receive heavy orographic (relief) rain

(ii) on the lee side of the mountains there is an area of rain-shadow.

(iii) a continuous belt of highland therefore acts as a climatic divide between the regions on either side.

(iv) mountains and plateaux develop special climates of their own—

(*a*) in low latitudes the main effect is a decrease of mean temperature with height

(*b*) in middle latitudes aspect becomes more important

(*c*) in higher latitudes severe climate on the high ground limits cultivation to low levels

(*d*) where there is a great range of height, there is a range of climate, wild vegetation, and farm crops from low levels to high. This feature is especially marked in low latitudes, where the summits may be permanently snow-capped while the lowland is under rain-forest

Topics for discussion

1 Explain why there is permanent snow in the Alps and in the Andes, but not on the mountains of Scotland.

2 In the Alps, farmland occurs as high as 17,000 feet above sea-level, whereas in the mountainous districts of the British Isles it is restricted to the lowest ground. Account for the contrast.

3 Describe the attractions offered to tourists by the Swiss Alps, the Rockies, or the Southern Alps, and draw a map to show the location of some of the main tourist centres.

4 A summary of the effects of high ground upon climate is given above. Discuss the principles stated in that summary with reference to (*a*) the mountainous parts of Britain; (*b*) the North American Cordillera; (*c*) the mountain backbone of the Scandinavian peninsula.

5 It is often said that the inhabitants of mountain regions differ from peoples of neighbouring lowlands. Can you give any examples of such a difference and suggest reasons for it?

6 If you live in or near a hilly district, can you discover any local examples of the effects of aspect?

Chapter Twelve

THE EARTH'S SURFACE

THE appearance of any piece of the Earth's surface depends on more than one factor. First, the simplest relief map shows that some areas stand higher than others, and we can, in fact, make a useful distinction between highland and lowland. Similarly, in the ocean there are parts where the water is generally shallow, and parts where it is very deep. Secondly, some land areas are broken by numerous valleys and possess little flat land. In others the valleys are wide apart and shallow. Some of the land surface has been eroded by ice, and some, in desert climates, sand-blasted. Thirdly, the rocks that form the crust of the earth differ from one place to another, and affect the kind of scenery that is developed on them.

Summarising, we can say that in considering the physical aspect of the land we must deal with three things:

1 The origin of the land itself, and the nature of the rocks that compose it
2 Relief
3 The effects of erosion

The study of the first of these topics is the science of geology, while the study of the second and third topics forms the science of earth-sculpture.

I The land

Much remains to be discovered about the interior of the Earth. We cannot see more than parts of the outer skin. However, it is fairly certain that there is a strong crust about forty-five miles thick, with a much weaker layer beneath it. The land on which men live consists of those parts of the crust which stand high enough to rise above the level of the sea.

Although the crust seems firm and solid to us, it can be bent, crumpled, and broken. Parts of it rise and other parts sink. But the movements are so slow in terms of human time that most of them are scarcely noticed. It is only the violent disturbances of earthquakes or volcanic eruptions that attract attention, and these are only minor episodes in a long history of crustal movement.

Rocks. Any constituent of the Earth's crust is a rock. The loose sand or the soft mud on the seashore is just as much rock as is the hardest stone used for building. Rocks are formed in two ways : some of them solidify from a molten state while others are formed from sediment. Both kinds can be greatly altered by heat or pressure—so greatly that their nature is entirely changed.

Igneous rocks are those which were once molten. Presumably the earliest rocks of all were of this kind, for at one time the entire Earth was hot and fluid. We know little of this portion of Earth history, however : there has been a solid crust for at least 3,000 million years. During this vast period all trace of the first beginnings of the land has been lost.

The igneous rocks that can be seen today have either been poured out at the surface as lava, or have set solid underground. Because they were once liquid, igneous rocks are *crystalline.* They consist of crystals of different substances which formed as the liquid rock cooled and solidified.

Granite is a well-known example. It solidified at great depths, cooled slowly and formed large crystals. Together with other coarsely crystalline rocks it is widely used in building (especially for ornamenting shop fronts) and for tombstones. These rocks are chosen for being hard and strong and for taking the high polish which makes them attractive. Solidified lava is widely represented by the blackish, heavy rock called basalt. Basalt forms the Giant's Causeway in Antrim, and underlies the cotton-growing region in the hinterland of Bombay. In the molten state it flowed out of long cracks in the crust, cooled rapidly and formed small crystals which are best seen with the help of a microscope.

Sedimentary rocks are formed of material worn off the surface of the Earth—that is, of the broken-down waste of earlier rocks. The great bulk of sedimentary rocks was laid down in the sea, which receives the sediment of rivers.

Sedimentary rocks are arranged in layers or beds (Pl. 11). Frequently they contain fossils—the remains of plants and animals. There are three main types that are formed in the sea, as follows :

(i) sandstones, which consist of sand grains naturally cemented together
(ii) limestones, which are composed of calcium carbonate, often in the form of shells, also cemented together
(iii) clays, which are of much finer grain ; they are made of minute particles and are not cemented

In favourable conditions the carbon of living matter may be preserved. Coal is a rock formed from the débris of plants which grew in swamps. The leaves and stems were protected from rotting by the marsh-water, and accumulated to depths of many feet in places. Later they were buried by other sediments and were compressed into coal as we know it today.

Mineral oil also represents the remains of living things, but has become liquid instead of solid. Like natural gas and natural asphalt, which are related to it, oil can move upwards through coarse-grained rocks, and may not be found at the level where it first formed.

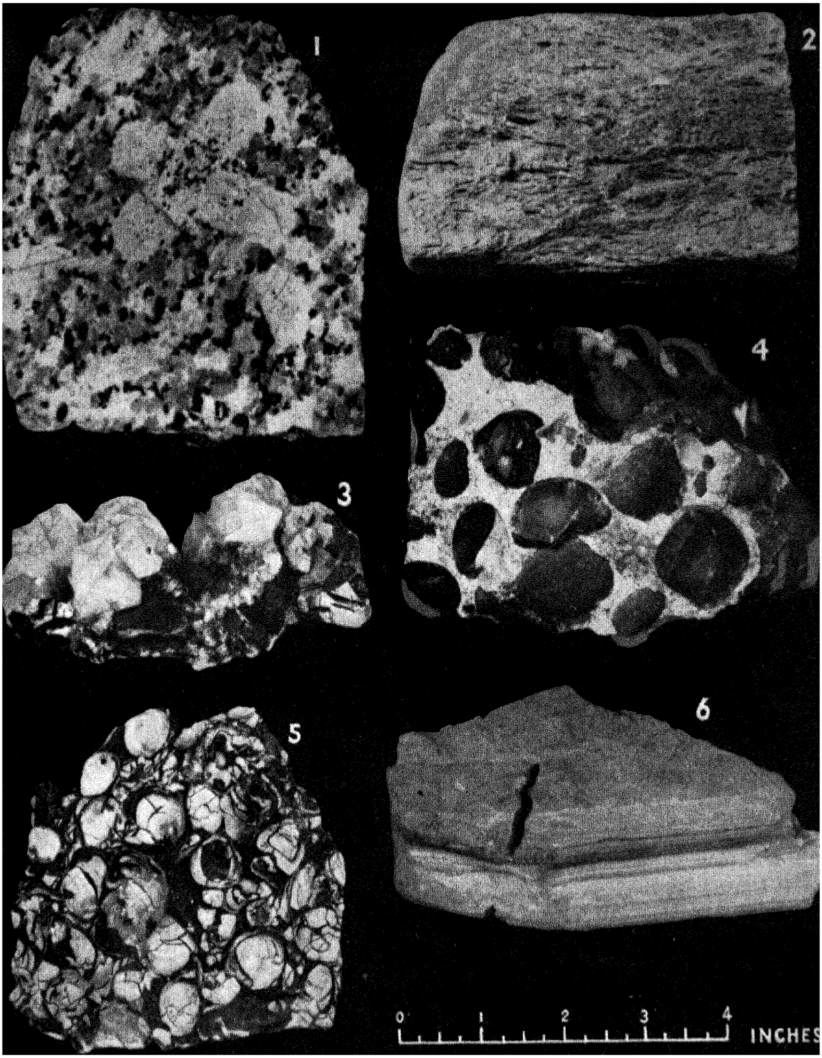


Plate 11 VARIOUS TYPES OF ROCK. 1, 2, and 3 are of igneous origin ; 4, 5, and 6 are sedimentary.

1. Granite. This rock formed at great depth beneath the surface of the earth, cooling very slowly from the molten state. There was time for crystals to grow large, and the rock is consequently coarse in texture. Crystals of three different kinds appear, respectively white, grey, and black in the picture. 2. Pumice—solidified frothy lava. The lava, pouring out at the surface, cooled too quickly to allow crystals to form, and the rock is glassy. It encloses bubbles which are drawn out in the direction of flow. 3. Crystals from a vein into which hot liquids were injected. Crystals of calcite (calcium carbonate) are light in colour, those of lead ore are dark. 4. Conglomerate, consisting of pebbles naturally cemented together by fine sand. It was laid down as gravel, with sand filling the spaces between the pebbles. 5. Shelly limestone. The broken sea-shells of which this rock is mainly composed accumulated in shallow water. They are cemented together by limy mud. 6. Clay. This specimen clearly shows the arrangement of fine-grained sediment in thin layers.

Sediments formed on the surface of the land include the sands of ancient deserts, and the varied deposits left by ice. These two classes are dealt with in later chapters.

Hardening of rocks. When sediments are first deposited they are soft. They harden into stone under the weight of additional sediments above them. They are also cemented by material dissolved in the water that percolates through them. There are great differences in strength between different kinds of rock. In a general way all rocks tend to become harder with age; the ancient sediments found in Wales and the Pennines are more resistant to erosion than the younger rocks of the English lowlands.

Alteration of rocks. Rocks are most effectively hardened by heat and pressure. The oldest known rocks have been intensely folded and strongly heated. They were deeply buried by later rocks, and depressed to levels where the Earth's interior heat could affect them. Rocks which have changed their nature because of heating or compression, or both, are given the name *metamorphic*. Some of them, e.g. those in the Scottish Highlands, are extremely resistant to erosion. The alteration of rocks is a very complex matter, but two examples may be offered to illustrate the nature of the changes. If clay is strongly compressed by movements of the Earth's crust it becomes slate. Limestone under strong pressure becomes marble. Slate and marble are both more resistant to erosion than the original sedimentary rocks.

2 and 3 Relief and Erosion

These two topics form the subject of the remainder of this book. The following remarks are merely introductory.

Much of the world's land surface is based on rocks that were formed in the sea, as can be proved by the marine fossils which they contain. It is evident that in some way the lands have been uplifted. The cause of uplift is not clear: it lies in forces operating in the unexplored interior of the earth, below the crust.

We know, however, that the strong crust has been subject to crumpling and breaking from time to time, and for the present purpose it is enough to note that these movements have occurred. Uplift has also taken place from time to time. Some parts of the crust have been uplifted more than others. All the great mountain belts owe their height to uplift. The next chapter describes the greatest uplifts of all.

As soon as uplift occurs the land surface is attacked by agents of erosion. Since some rocks are stronger than others and are better able to withstand erosion, the land is worn down in an irregular fashion. The weak rocks are speedily removed and wide valleys are cut in them. The stronger rocks, on the other hand, tend to form upstanding features of the landscape.

Topics for discussion

1 Make a collection of local rocks. Specimens should be collected from the rock in place, and should be large enough to be recognisable.

2 If there is a local museum, or if you live within reach of a large museum, pay a visit to the geological collection.

3 Make a study of the kinds of rock used locally for (*a*) building houses; (*b*) decorative work on public buildings and shop-fronts; (*c*) tombstones.

4 Make a collection of local fossils, and if possible study the fossils displayed in a local museum.

5 Locate any quarries in your district where rock is worked for sale. Find out what kind of rock is being extracted, and what it is used for.

6 Preferably with the aid of a geological map, discover in which parts of your home district weak rocks have been much eroded. On what kinds of rock is the high ground based?

7 If you can see the local rocks in section, as in a quarry or on a cliff, trace with explanatory diagrams the effects of weathering along joint-planes.

Chapter Thirteen

FOLD MOUNTAINS: THEIR ORIGIN AND DESTRUCTION

ON the world map (Fig. 25) one symbol has been used for all the young fold mountains. Two great belts exist. One runs along the western side of the Americas, the other stretches from Spain to Japan.

The American system, beginning in Alaska, includes the North American Cordillera, the island chains of the West Indies, and the Andes which extend to Cape Horn. The young fold mountains of the Old World start at the western end of the Mediterranean. They run east through the Alps, the Apennines, and the Balkan Peninsula, continuing through Turkey, the Caucasus, and the Himalayas. At their eastern end the Himalayas fan out, sending branches into China, through Indo-China and the East Indies, and connecting with the American system through the Philippines and Japan.

These highland belts are called *fold mountains* because the rocks in them have been crumpled by major disturbances of the Earth's crust. They are *young* because they belong to the last episode of mountain building. In the 3,000 million years that the Earth has had a solid crust there have been several periods of mountain-building; each lasted only a few million years,

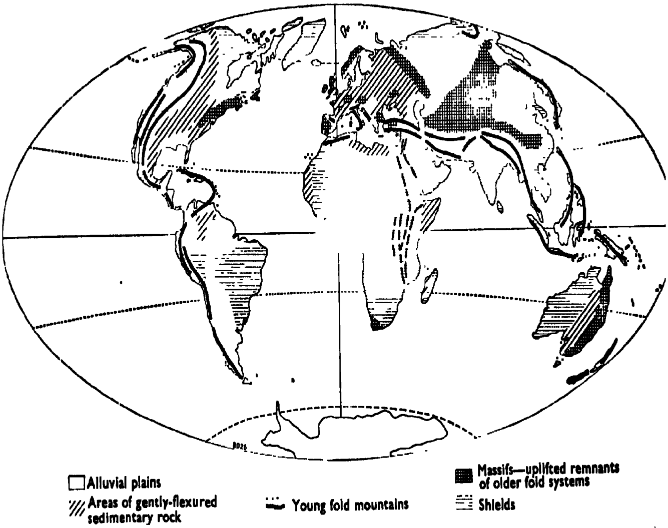


Fig. 25 SOME MAJOR CRUSTAL UNITS OF THE WORLD.

Plate 12 CASCADE MOUNTAIN, ALBERTA, CANADA. The snow lying on little shelves formed by resistant beds reveals the structure of the mountain, in which the rocks are downfolded. The upfolds on either side have been eroded away.

and they were separated by long spells of quieter conditions during which the high land was worn down.

1 The landscape of fold mountain belts

The photograph in Plate 12 was taken in the Cordillera of Canada. It shows Cascade Mountain, 9,826 feet high. Notice how snow near the summit outlines the fold in the rocks. The peak of the mountain is the *bottom* of a fold—evidently the remainder has been destroyed by erosion. This is a most important point: the height of mountains is due to uplift, but their shape is due to erosion.

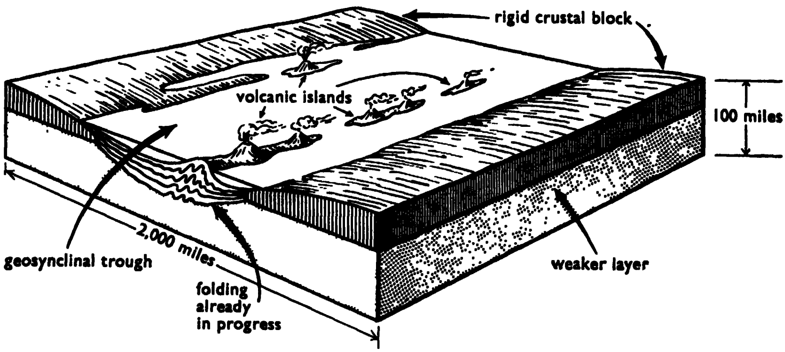
Erosion is vigorous in the young fold mountains. The land stands high above sea-level, rivers have steep gradients, and in cold climates frost also attacks the rocks. The result is a varied landscape of steep slopes and hard going. It is not surprising that such mountains are barriers to man, frequently forming the frontier between one country and another. They tend to be sparsely peopled, and their inhabitants are rather isolated from the rest of the world. Exceptions occur in scattered mining centres, and notably in the tourist areas of Alpine Switzerland.

2 The making of fold mountains

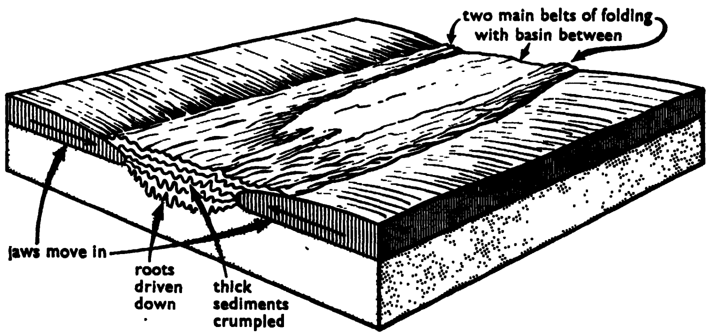
There are three stages in mountain-building—formation of the rocks, folding, and uplift.

(i) *Formation of the rocks.* Mountain-building starts with the sagging of a belt of the Earth's crust, thousands of miles long and hundreds of miles wide. This subsiding basin is a *geosyncline*—an enormous downfold. Rivers from the bordering lands bring down into it vast amounts of sediment, which accumulate to depths of many thousands of feet and are compressed by their own weight (Fig. 26*a*).

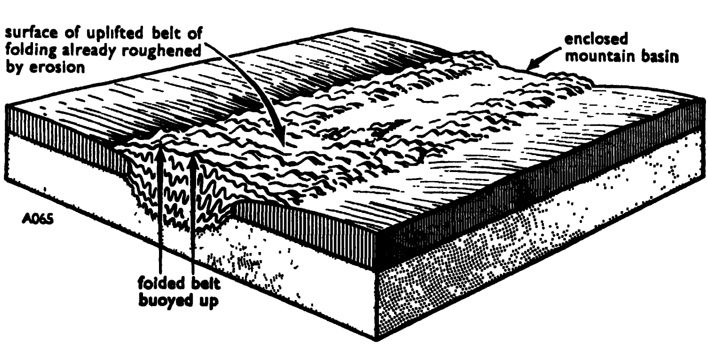
(ii) *Folding.* Sooner or later the sides of the trough start to close in. The thick sediments undergo complex folding (Fig. 26*b*). In the Alps, as the diagrams show, pressure from the sides was very great and the sedimentary rocks were tightly squeezed, but



(*a*) The beginning of mountain-building ; subsidence, sedimentation, and volcanic outbursts in a geosyncline.



(*b*) Closing of the jaws of the geosyncline and general crumpling of the sediments.



(*c*) General uplift, converting geosynclinal belt to fold mountains.

Fig. 26 MOUNTAIN-BUILDING.

elsewhere, e.g. in Turkey and in the North American Cordillera, folding was concentrated near the edges of the trough and less disturbed areas remained between the belts of crumpling. The ruckled floor of the geosyncline is driven deeply down, as ***mountain roots***, into the yielding rocks beneath the crust.

Volcanoes are likely to break out during the folding, for molten rock is able to find its way to the surface through the weak sediments of the geosyncline. The liquid pours out as ***lava***. Gases—mostly steam—escape from the vents, blowing out fragments of broken rock and building volcanic cones. An atlas map of volcanoes shows that many lie within the belt of young fold mountains—Fujiyama in Japan, Vesuvius and Etna in Italy and Sicily respectively, and the great volcanoes of America, e.g. Popocatapetl, Chimborazo, and Cotopaxi (Fig. 32*b*).

(iii) *Uplift*. When pressure from the sides of the geosyncline is relaxed the folded belt rises. It is buoyed up by the mountain roots, which consist of sedimentary rock and are light as rocks go. It is this uplift that accounts for the height of young fold mountains (Fig. 26*c*).

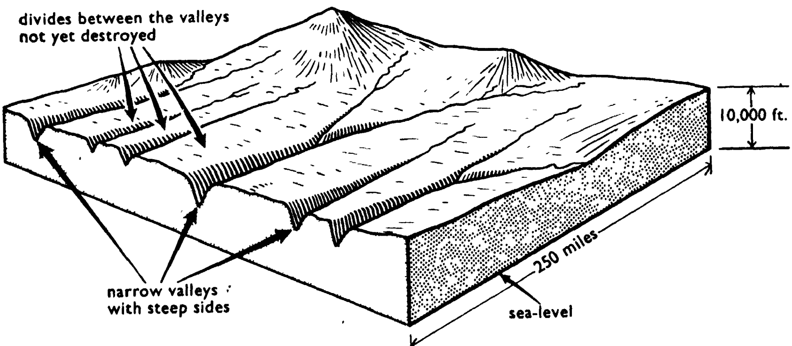
3 Erosion of the rocks

No sooner does uplift start than the attack of erosion begins. At first it is slow, but as time goes on the land is more and more deeply cut. In time the mountains will be worn right down to the roots, and the land reduced to low-lying plains. The sequence of events from uplift to the destruction of the highland is called the *cycle of erosion*.

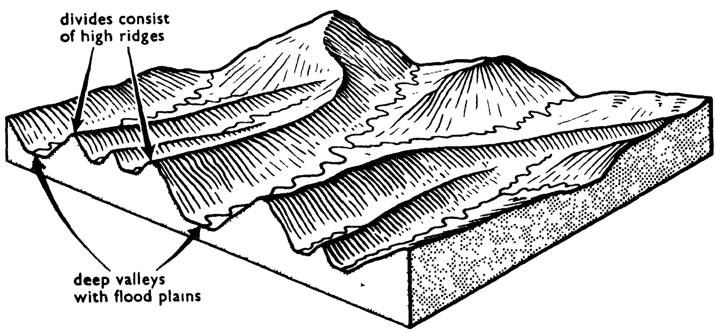
(i) *Weathering* is the breaking and rotting of rock. Climate determines which shall be the more effective. In humid climates water produces chemical changes, and the rocks become softer and less coherent. In dry climates alternate heating and cooling shatter the exposed rock. In cold climates ice forms in cracks, expanding as it does so, and rock-breaking again results. As glacial and desert landscapes are described in separate chapters we shall be mainly concerned here with humid areas, where, although temperature changes and frost action have some effect, weathering is due mainly to the chemical action of water.

(ii) *Erosion* takes place when broken or rotted rock is removed, either in a solid state or in solution. The material goes to form new deposits. Some of it finds a temporary resting-place on the land or on the shore, but eventually the bulk of it forms new rocks beneath the sea. The *agents of erosion* are: (*a*) wind—most effective in arid climates; (*b*) moving ice, which is confined to cold regions; (*c*) running water—rainwash over the surface and rivers in distinct channels. We shall consider (*a*) in Chapter 19 and (*b*) in Chapter 18, and turn here to (*c*).

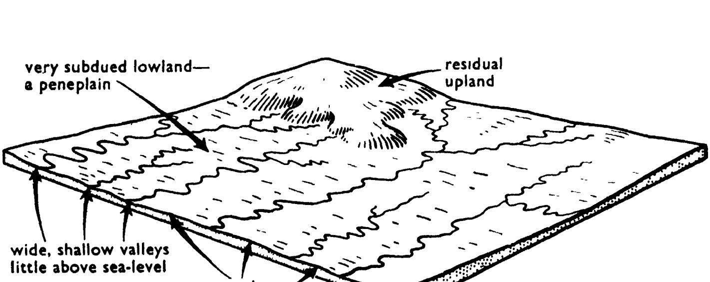
Plate 13 A YOUNG LANDSCAPE. In the distance large portions of the original surface survive as extensive flat hilltops. The almost vertical parts of the valley walls are based on strong, coherent rock. The gentler slopes below are on weaker rock, where some soil is present and trees are able to grow. The largest valley is Zion Canyon, Utah.



(*a*) A landscape in the stage of youth.



(*b*) A landscape in the stage of maturity.



(*c*) A landscape in the stage of old age, most of it reduced to a peneplain.

Fig. 27 THE CYCLE OF EROSION.

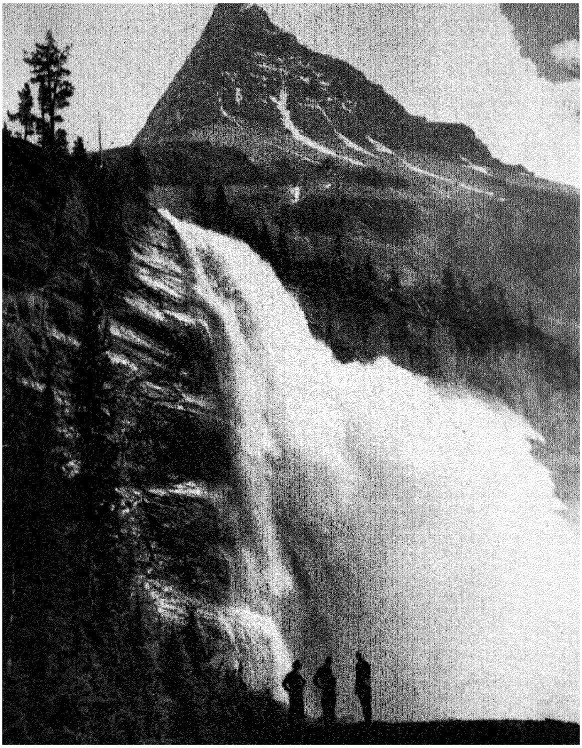
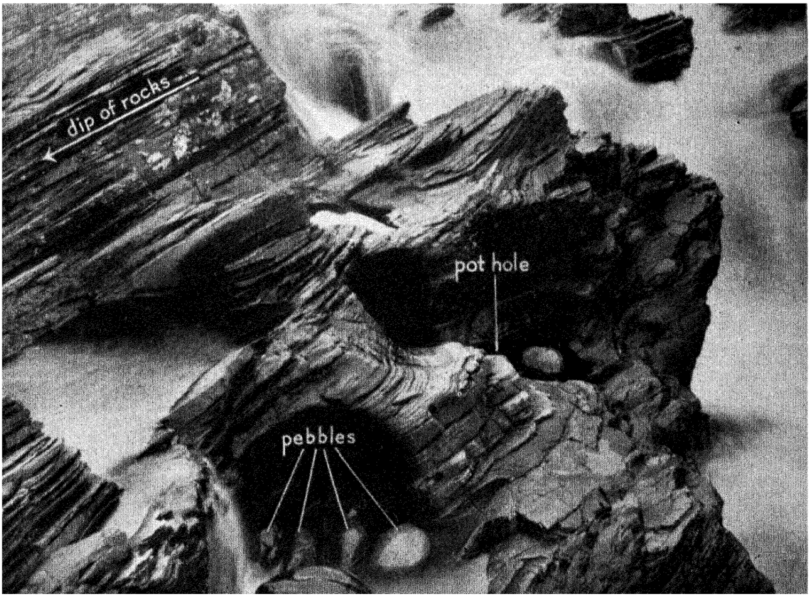


Plate 14 EMPEROR FALLS, JASPER NATIONAL PARK, CANADA. These falls make a pronounced irregularity on the long profile of the river, which is far from being mature in the present cycle of erosion. Waterfalls and rapids of various sizes are typical of a young river.

Plate 15 POTHOLES IN THE BED OF THE RIVER LYON, GLEN LYON, PERTHSHIRE. Rock-fragments swirled round in hollows are rounded into pebbles, and round holes are drilled into the bed.



4 The cycle of erosion by running water

In the cycle of erosion there are three stages :

(i) *youth*, when parts of the uplifted surface are still intact
(ii) *maturity*, when all the original surface has been destroyed
(iii) *old age*, in which the landscape is worn down to low levels

(i) *The stage of youth.* Study carefully the photograph in Plate 13. The landscape is one of deep, narrow valleys with broad, flat hilltops between them. There has not yet been time for the valleys to develop wide floors. Their sides are being worn away by weathering, and the weathered material is creeping downhill, but extensive flat summits still survive. This landscape illustrates the *stage of youth* (Fig. 27*a*).

A youthful landscape makes communications difficult. The obvious way to high ground is up the valleys, but young valleys are typically narrow with little room at the bottom for anything but the rivers. The valley sides are steep and difficult to climb. It is true that the summits are flat, but they are very exposed. Roads and railways are expensive to build in country of this kind, and are rarely found except where they run to mines.

The rivers are of little help to travellers, for they are interrupted by falls and rapids. Plate 14 shows one of the thousands of falls in the Cordillera of North America. Ships are clearly useless on rivers of this sort, while travel by canoe means carrying the craft and the cargo past every fall. Young rivers have steep gradients and cut rapidly downwards. Their load of broken rock wears away their beds. Potholes (Pl. 15) are drilled into the bottom of the channel where pebbles are swirled round in hollows. Very rapid downcutting can produce a *gorge* (a valley with vertical sides) ; deepening is so fast that there is no time for the walls of the valley to be weathered away.

(ii) *The stage of maturity.* In time, however, the valleys are widened and the whole of the original land surface is eroded away. The landscape now consists of deep valleys separated

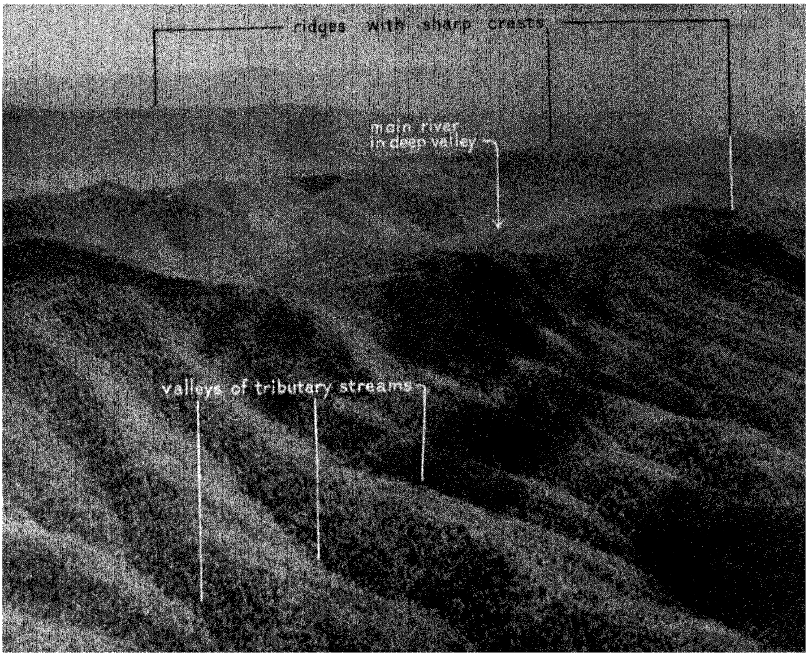


Plate 16 A MATURE LANDSCAPE IN THE MOUNTAINS OF VIRGINIA. The ridges rise to the general level at which the land surface stood before deep valleys were eroded in it. Now all that remains of the plateau is a series of even crests at the tops of the ridges (contrast Plate 13).

by high ridges with pointed tops (Pl. 16 and Fig. 27*b*). By this stage the larger rivers have developed extensive systems of tributaries, and their valley floors are wide and flat. Gradients along the valleys are gentler and more regular than in the stage of youth, and natural routeways lead into the highlands. Falls and rapids have been worn away (Fig. 28), so that some streams are now *graded*—they have no pronounced irregularities in their profiles.

Many rivers in a mature landscape flow over *flood plains.* A flood plain is the flat strip of ground in a valley bottom, alongside a river, that is covered with water in time of flood. It is formed by a *meandering stream*—that is, a stream with a winding course (Fig. 29). Very many streams meander, beginning to do so in the stage of youth, but it is in the smoothly sloping mature valleys that meanders develop best. The individual meanders tend to shift slowly downstream. In due course, therefore, the whole valley bottom is worked over and is covered with a layer of alluvium. At high water stages the main channel

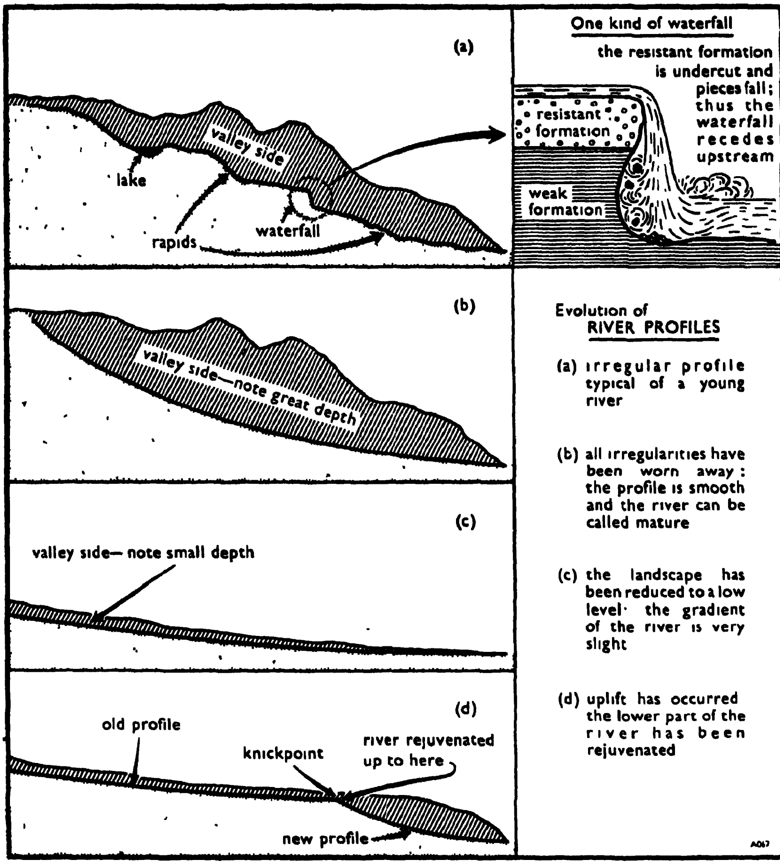
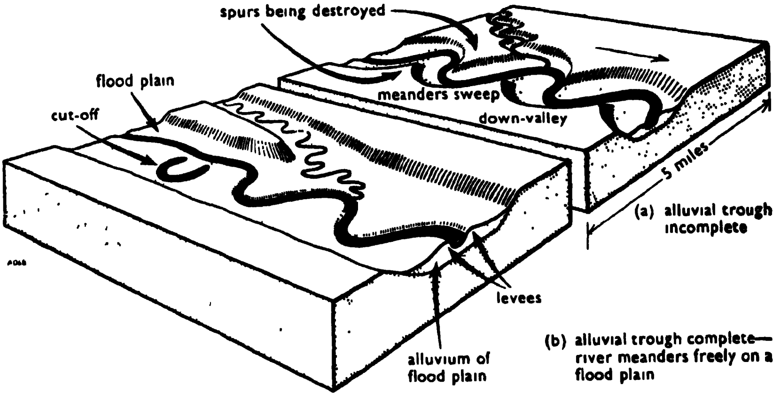


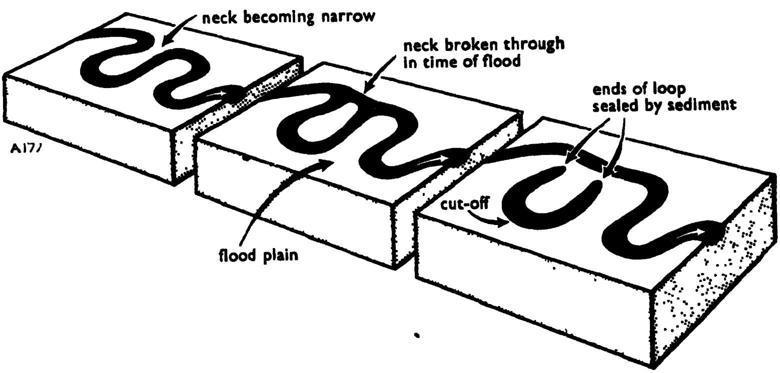
Fig. 28 RIVER PROFILES.

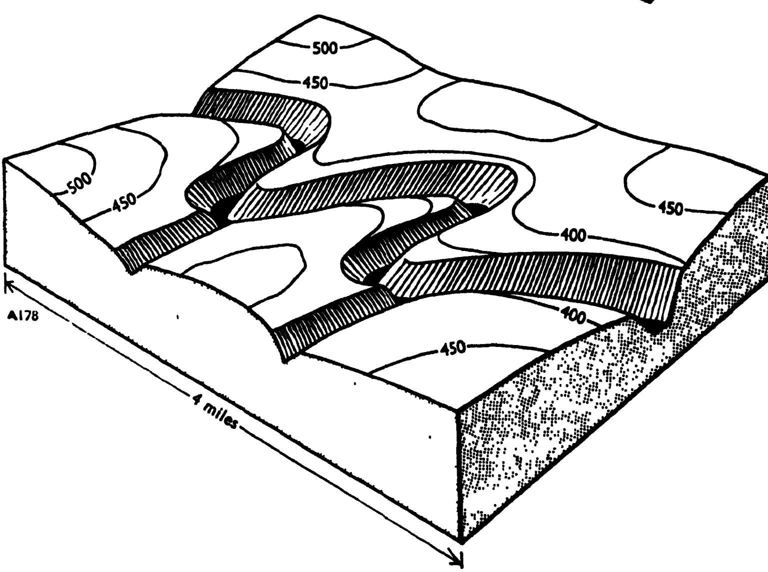
Fig. 29 (*opposite, top*) FORMATION OF AN ALLUVIAL TROUGH BY A MEANDERING STREAM.

Fig. 30*a* (*opposite, middle*) DEVELOPMENT OF A CUT-OFF ON A MEANDERING STREAM.

Fig. 30*b* (*opposite, bottom*) MEANDERS INCISED INTO A LOW PLATEAU. The two tributaries entering from the left are also incised.


spurs being destroyed
flood plain
meanders sweep
down-valley
cut-off
5 miles
(a) alluvial trough incomplete
levees
alluvium of flood plain
(b) alluvial trough complete—river meanders freely on a flood plain


neck becoming narrow
neck broken through in time of flood
ends of loop sealed by sediment
A177
cut-off
flood plain


500
450
500
450
450
400
400
450
A178
4 miles

cannot hold all the water that comes down, and the flood plain is submerged, receiving a deposit of sediment from the muddy water. Deposition is concentrated on the banks of the main channel, where *levees* form; they are often strengthened artificially to guard against the danger of flood. From time to time the neck of a meander is broken through, the abandoned loop plugged with sediment at its ends remaining as a cut-off (Fig. 30).

(iii) *The stage of old age.* By the stage of maturity rivers have cut well down into the land and can deepen their valleys but slowly. But weathering continues its work on the ridges, where the rotted rock still moves downhill. Rainwash and *creep* carry it into the streams which transport it towards the sea. In old age, then, the hills are worn away. The whole landscape is reduced to a low level. The uplifted mountains have been destroyed and their roots are exposed at the surface (Fig. 27*c*).

Topics for discussion

1 Explain what happens when a volcano erupts, illustrating your answer by a sketch of an actual volcano.

2 Make a study of a local stream, finding out whether it is cutting potholes in its bed, whether there are waterfalls and rapids on it, and whether it meanders.

3 Draw a sketch-map, from observation on the ground, to show part of a flood-plain.

4 Referring to an actual stream, say on which side of a meander the bank is steeper. What happens on the opposite side?

5 Not all rivers flowing on flood plains build levees. Name some rivers which do, and explain what happens when a river bursts its banks.

6 Draw a sketch of a cut-off, either from an example seen in the field or from a map.

7 Choose an example of a waterfall, and explain how it is caused.

Chapter Fourteen

MASSIFS AND THE RENEWAL OF EROSION

In the previous chapter the history of a fold-mountain belt was briefly summarised, from the formation of the rocks, through uplift and erosion, to the destruction of the highland. The landscapes of the fold mountain district illustrated in Plate 16 are still in the stage of youth or of maturity, for there has not yet been time for them to be reduced to lowlands. But as was said above —on page 94—other and older fold-mountain systems were formed in earlier geological eras. They have all been worn down to low levels. Their history did not end there, however —parts of them were again uplifted and erosion attacked them with renewed force.

All the highlands of western Britain are remnants of old fold mountains of various ages. Their landscapes today comprise blocks of high ground separated by lowlands or by inlets of the sea. The Southwest Peninsula of England, the Welsh Uplands, the Pennines, the Lake District, the Southern Uplands, the Scottish Highlands, and the mountainous regions of Ireland are all remnants of anciently folded belts. In a world view certain enormous crustal blocks stand out prominently. These are the *shields* (Fig. 25). They consist of the severely eroded remains of very ancient mountain systems.

Plate 17 VIEW SOUTHWESTWARDS ALONG THE GREAT GLEN, SCOTLAND. In the foreground is Loch Oich, separated by a strip of low ground from Loch Lochy in the centre distance. The far end of Loch Lochy is about fifteen miles away. The mountains on the right centre rise above 3,000 feet, while the Ben Nevis group in the left distance reach well above 4,000 feet. Note the trough-like form of the Great Glen which has been scoured by ice, and the remarkable straightness which reflects the course of a huge fault in the crust.

I Massifs and plateaux

Considered as parts of the Earth's crust all these units are *massifs*, i.e. rigid blocks. They consist of old rocks which have hardened, either with age or through heating and compression. Considered as landscapes the regions are plateaux, i.e. areas of high ground with extensive subdued summits. Even where ice has been at work, sharpening their peaks, the plateau character can be made out. Many summits in the Scottish Highlands, for example, reach some 3,000 feet above sea-level.

The nature of massifs. The nature and origin of massifs are best explained by reference to a particular instance, e.g. south-western England. About 250 million years ago a belt of fold mountains was formed in Europe. It ran roughly from east to west, including the land that is now northwestern France,

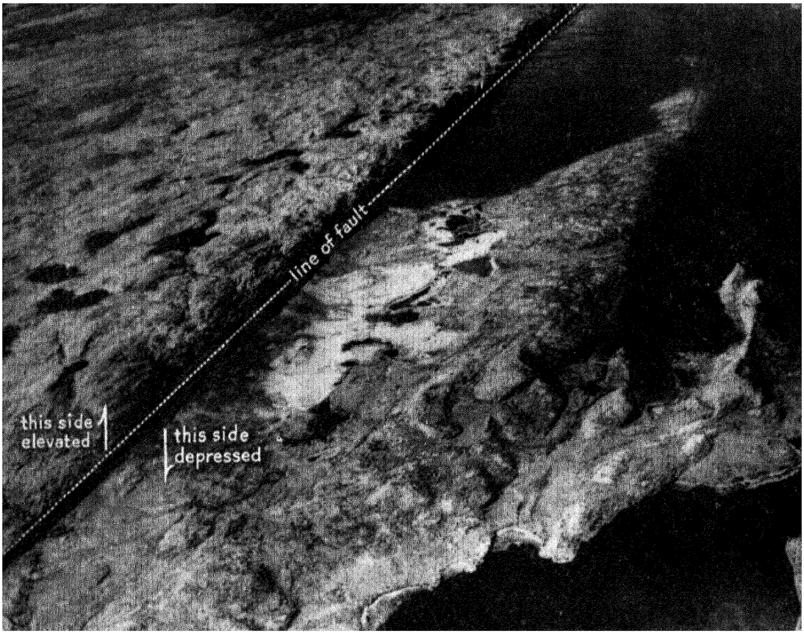


Plate 18 A SCARP DEVELOPED BY EROSION ON THE LINE OF A FAULT. This fault is sixty miles long, and the scarp rises in places to 300 feet. The lake covering part of the depressed block is MacDonald Lake in northwest Canada. It is surrounded by the bleak expanses of tundra country, where many small hollows are filled by water or peat ; trees grow only in sheltered places. This whole district has been heavily scoured by an ice-sheet.

southwestern England, South Wales and southern Ireland. Most of the rocks were thick sediments—sandstones, limestones, and clays—that had been laid down in a geosyncline. As in all mountain building, when the sediments were crumpled, roots were driven far down ; masses of molten rock invaded them and set solid in crystalline form.

When the mountains were destroyed by prolonged erosion the roots were exposed at the surface. We now see the crystalline rocks as the granites of Dartmoor, Bodmin Moor, and similar hill districts ; other masses of granite appear at the surface in northwestern France. Veins, including ores of copper and tin, have been injected into the neighbouring sedimentary rocks around the granite. The sediments themselves have been altered by heat and pressure. The well-known slates of Delabole, for example, were once clays.

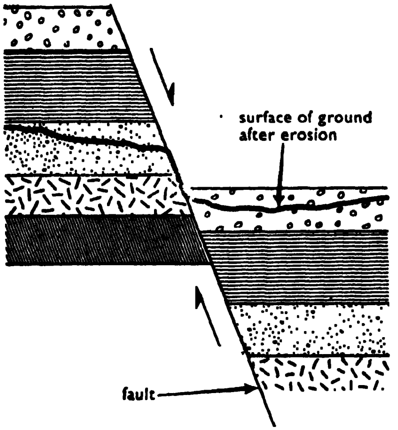
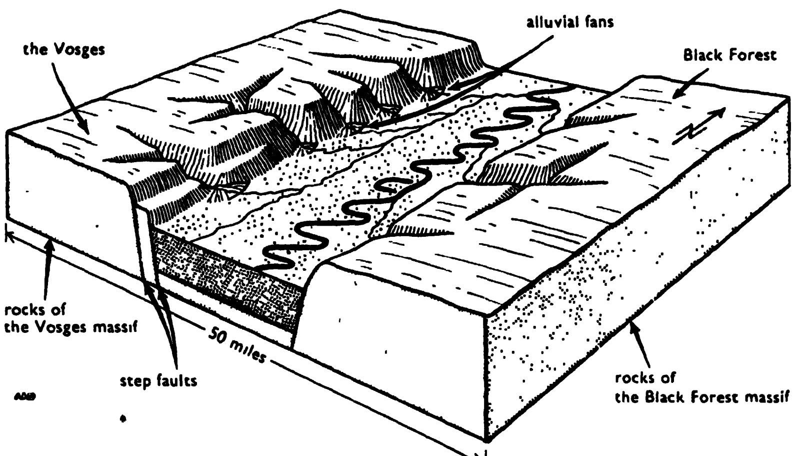


Fig. 31*a* (*left*) DISPLACEMENT OF THE CRUST BY A FAULT.

Fig. 31*b* (*below*) THE RHINE RIFT VALLEY.

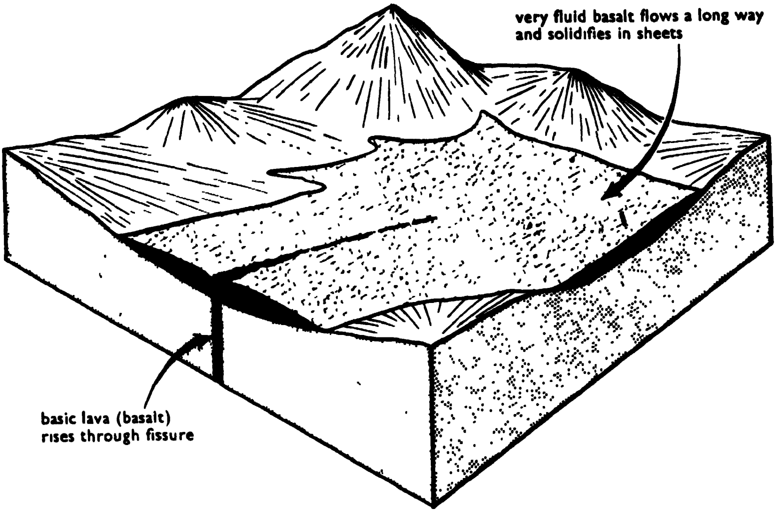
Fig. 32*a* (*opposite, top*) ONE FORM OF VOLCANIC ACTIVITY : the formation of basalt sheets by the escape of lava from fissures. Impressive sheets of basalt occur in Antrim.

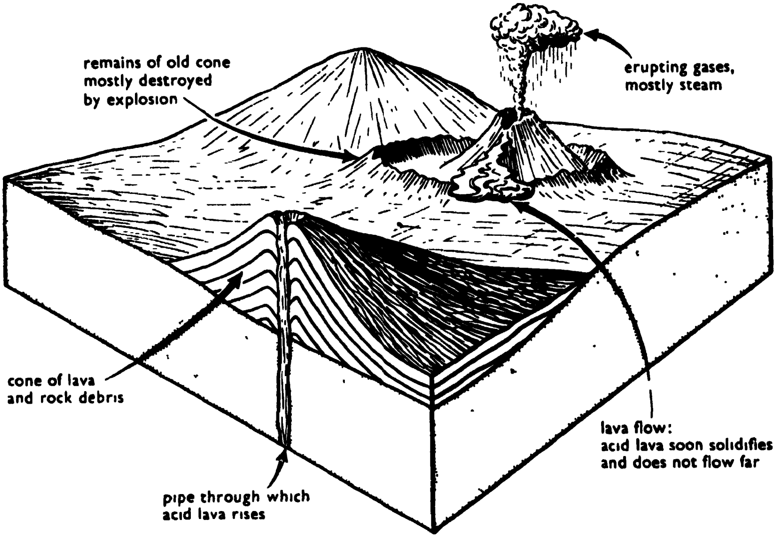
Fig. 32*b* (*opposite, bottom*) ANOTHER FORM OF VOLCANIC ACTIVITY : eruption of localised vents. Vesuvius provides an excellent example.



In these various ways the crust was strengthened throughout the mountain belt. When renewed movement of the crust occurred the rigid belt could no longer fold, but was broken into separate blocks. Some of these subsided and were buried by newer sediments. Others were raised and formed highland. We see, then, that massifs are high because they have been uplifted, and that they resist erosion because they are composed mainly of strong rocks. The cycle of erosion proceeds slowly there, and they rise sharply from the adjacent lowlands, which are based on less resistant rocks.

Faults. A fault is a break in the crust of the Earth (see Fig. 31*a*





and Pl. 18). Faults can occur anywhere, but their effect on the landscape is greatest in massifs—there they are lines of weakness in an area of crustal strength. Many of them have been picked out by erosion. The most remarkable one in Britain is the Glen More Fault, which runs straight across the whole width of Scotland. Rivers and ice have cut a valley along the entire length of this fault, making a deep gash that penetrates the

Highlands from side to side (Pl. 17). The huge fault in Plate 18 is located in the Laurentian Shield of Canada, one of the great and ancient massifs mentioned above. This fault, too, has been revealed by ice erosion. In the Central Plateau of France and elsewhere some lines of faulting are associated with volcanoes, for molten rock has welled up the fissures and has reached the surface (Fig. 32).

In some places a strip of country is let down between parallel faults as a *rift valley* (Fig. 31*b*). The best-known European example is that drained by the Rhine above Bingen. An enormous system of rifts contains the long, deep lakes of East Africa, the Red Sea, the Dead Sea, and the Jordan Valley. Britain has nothing on this scale, but we may note that Central Scotland has been let down between the Highlands and the Southern Uplands.

Along the line of a fault the crust may be displaced by thousands of feet. Movement is very slow, however, in terms of human time, taking place a few inches or a few feet at a time. The shock-waves set up when the blocks move are *earthquakes*.

2 The nature of plateaux

The highest ground of southwestern England (to return to the chosen example of a massif) consists of high, open moorland (Pl. 19). Soil drainage is poor because the slopes are so gentle, and the countryside is exposed to the full force of the wind. There is much wild vegetation of coarse moor grasses, heather, and peat bog in the hollows. Peaty moor is typical of much upland country in western Britain. The subdued summits are due to prolonged erosion at some earlier time, when the land stood lower than it does now; the gently sloping surfaces are preserved because the rocks are resistant.

3 Renewed erosion

Around the edges of plateaux can be seen the results of renewed erosion. The rivers of southwestern England have cut deeply down in their lower courses, eroding narrow valleys with steep sides. The landscape has once more become youthful. It is said

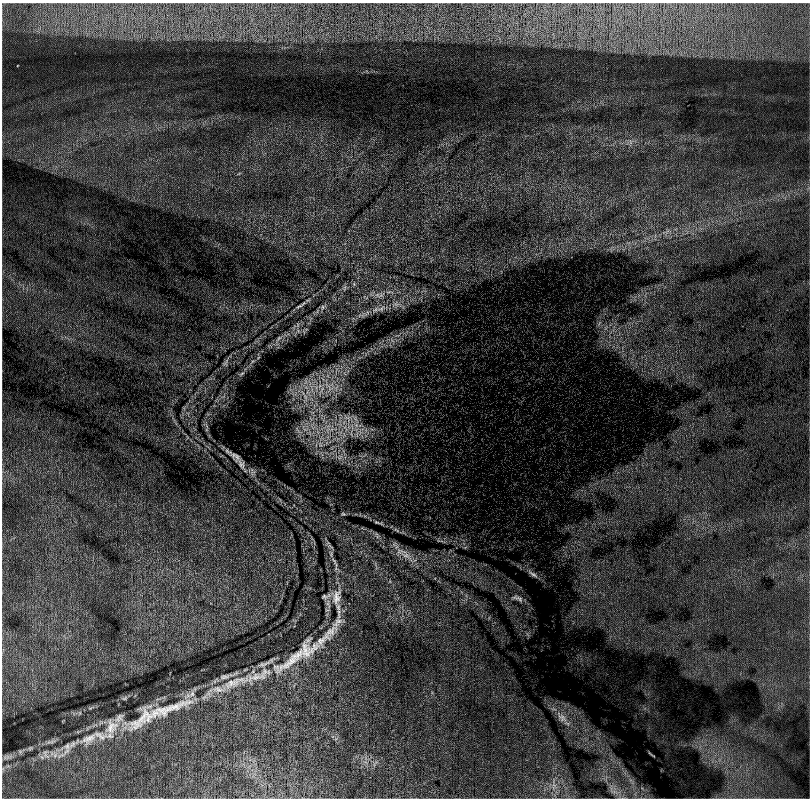


Plate 19 VIEW ON DARTMOOR, showing subdued plateau country cut into by a narrow, steep-sided valley. The valley is still in the stage of youth, while the plateau surface is part of a landscape which reached the stage of old age in a previous cycle.

to be *rejuvenated.* It combines the young valleys that are now being cut with the gentle slopes of old age produced in an earlier cycle of erosion.

Causes of renewed erosion. Erosion starts again with renewed vigour when the land is uplifted or when sea-level falls. Both processes have affected the southwest of England.

Effect on rivers. Compare the two river profiles shown in Figs. 28*b* and 28*d*. One is the smooth profile of a graded stream, related to a stable sea-level, the other includes a marked break. This is the product of renewed erosion. An uplift of the land, or a fall of sea-level, has made the river cut rapidly downwards near the mouth, developing a new profile which is gradually

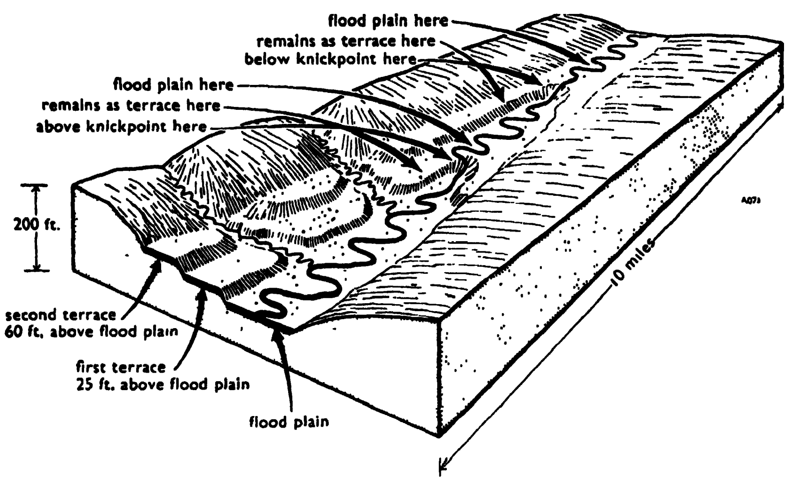


Fig. 33 THE ORIGIN OF RIVER TERRACES. The heights given are those of the main terraces in the Thames valley ; but the form of the diagram is based on the narrow valley of the Lea, a tributary of the Thames.

extended upstream. The new profile meets the remaining part of the old profile in a *knickpoint*, which may be visible on the ground as a waterfall or as rapids. Below the knickpoint the old valley floor may continue as a terrace (Fig. 33).

The larger rivers of the southwest have been affected by several falls of sea-level, and their profiles show several knick-points. Vigorous downcutting has *incised* the rivers into the strong rocks of the massif (Fig. 30*b*).

Changes of sea-level in other areas. A rise or fall of sea-level must affect the whole of the oceans, whereas rising or sinking of the land may be only local. Movements of the land occur mainly where the crust is unstable, as for instance in North Island, New Zealand ; but because of general movements of sea-level very many rivers throughout the world have been rejuvenated. Knickpoints appear in their profiles and terraces are present in their valleys.

4 Massifs in Human Geography

In high and middle latitudes settlement in massifs tends to be sparse because of the cold and exposure, but within the Tropics height may be an advantage, especially to people of the white nations, in mitigating heat. At very high levels, however, the cold rarefied air and exposure to strong winds can make plateau country difficult and uncomfortable to live in. The enormous plateau of Tibet, with the Himalayas along its southern edge, is notably isolated from the outside world. The plateaux enclosed in the high mountain basins of the Andes are similarly cut off to a large extent. Much depends, however, on the nature of the rocks themselves. Let us take two contrasting examples from the massifs of Britain, those areas where coal is present, and plateau country based on limestone.

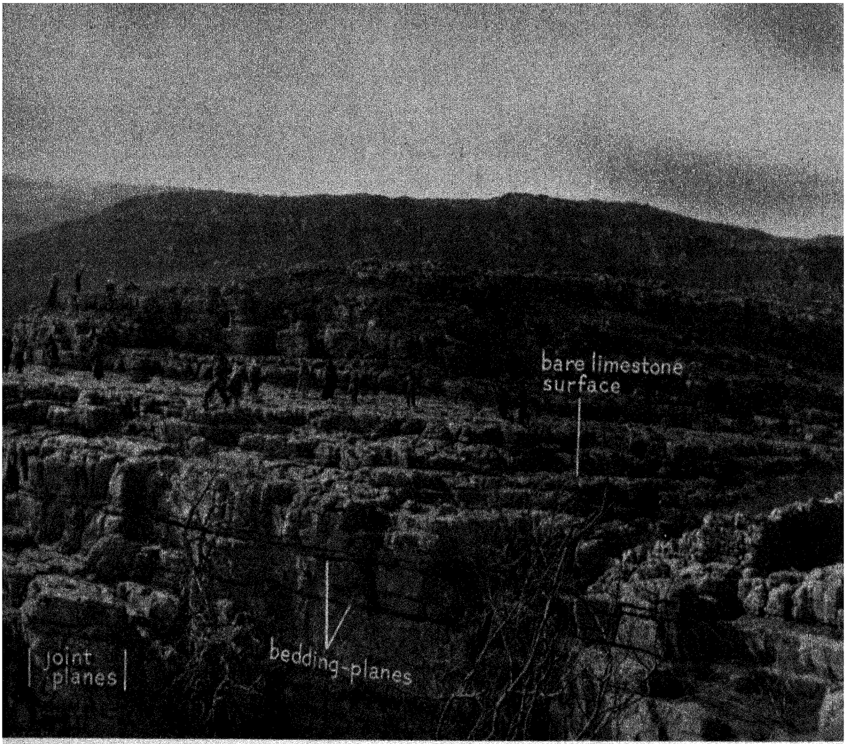
(i) *Coalfields.* All the great coalfields of Britain lie on the flanks of massifs. The Coal Measures were formed early enough to be included in the folded belts which were to be levelled by erosion and later uplifted as rigid blocks. Mining and industrial towns, with their dense populations, therefore occur within the boundaries of the plateaux. Contrast with such regions the more thinly peopled southwest, where there is no coal. Agriculture is possible, however, on the open plateau tops except at the highest levels. But in Wales and more northerly plateaux the broad summits are too bleak for anything but sheep-grazing.

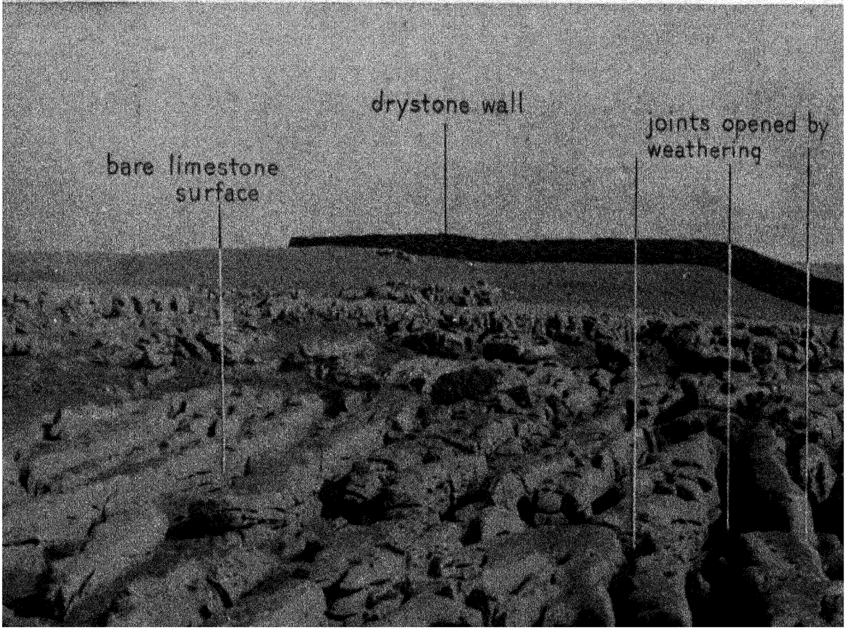
(ii) *Limestone country.* Parts of the plateau areas of Britain are based on a formation called Carboniferous Limestone. This comes to the surface, e.g. both in the South and in the North Pennines. Although it is a strong rock it is readily dissolved by water that percolates down the joints (Pl. 20). Consequently drainage goes underground. Streams disappear down swallow-holes, valleys are dry, and the bare limestone appears at the surface of the ground.

5 Summary

Summarising the character of massifs and the effects of renewed erosion, we may say that :

(i) the uplift of rigid crustal blocks produces *massifs*
(ii) their subdued summits, resulting from previous episodes of prolonged erosion, give landscape of the *plateau* type


bare limestone
surface
joint
planes
bedding-planes


drystone wall
joints opened by
weathering
bare limestone
surface

(iii) intermittent uplift or fall of sea-level have *rejuvenated* both the landscape and the rivers
(iv) plateaux cut by *incised valleys* are called *dissected plateaux*
(v) while the rocks of a massif are strong on the whole, important differences exist between different types

Topics for discussion

1 Draw a map of the British Isles or of another country familiar to you, and mark on it the massifs. Describe a scene in any one of these.

2 Explain what is meant by a rejuvenated stream, and illustrate your account by a sketch or map of a stream which has been rejuvenated.

3 Using a 1 inch to 1 mile O.S. map, draw profiles for streams draining southwards from Dartmoor or Bodmin Moor. Say what distinctive features you notice in these profiles, and suggest reasons to explain them.

4 Choose an area underlain by limestone, and describe its typical surface features.

5 Draw a contour map to explain the meaning of the term *dissected plateau*.

6 With the aid of a geological map, if one is available, locate a river terrace as close as possible to your home area. Contrast the use made of the terrace with that made of the flood plain, and account for the differences you notice.

7 In the plateau country of southwestern England, many roads run along the divides between the valleys. Confirm this statement by reference to the O.S. map, and explain why it should be so.

Plate 20 (*opposite*) LIMESTONE COUNTRY NEAR MALHAM, YORKSHIRE. (*top*) The rock is Carboniferous Limestone, which is well bedded and well jointed, and which here dips very gently. Surface water drains into fissures in the rock, carrying soil particles with it and leaving the limestone bare. (*bottom*) Closer view of limestone surface, showing joints greatly widened by solution.

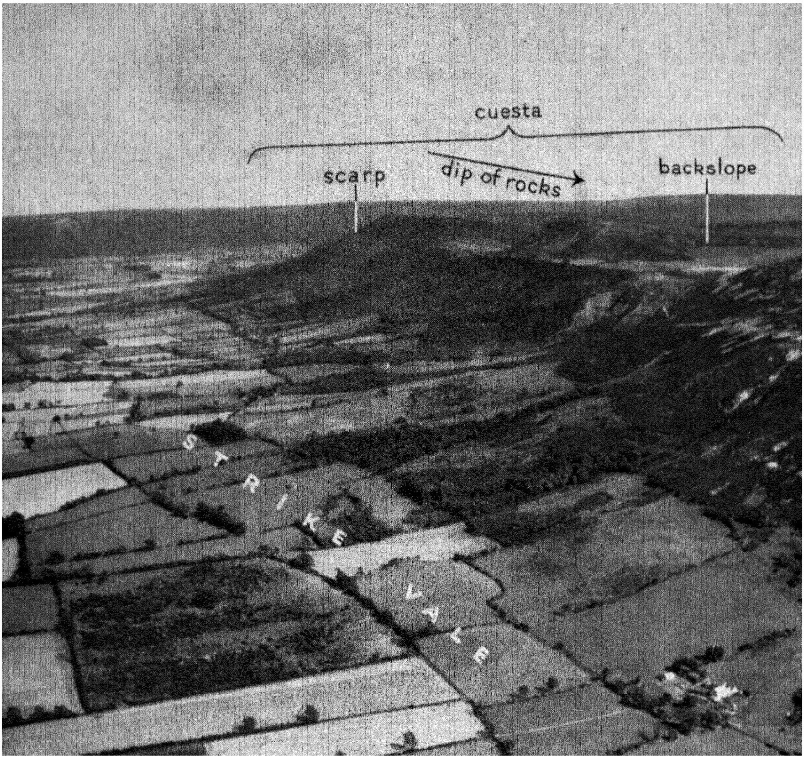


Plate 21 THE LANDFORMS OF SCARPLAND COUNTRY, seen in the Cleveland Hills, Yorkshire. The scarp is based on strong sedimentary rocks—mainly sandstones —while the strike vale is developed on weak clays which dip away under the sandstones.

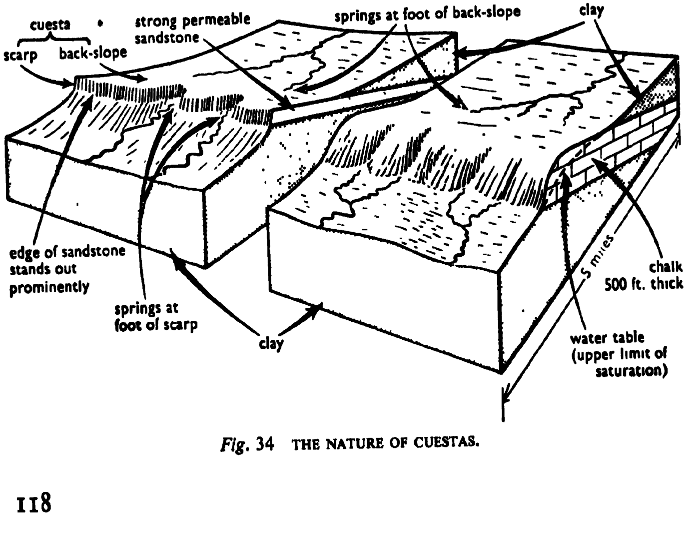


Fig. 34 THE NATURE OF CUESTAS.

Chapter Fifteen

LOWLANDS: I, SCARPLANDS

In human geography particular attention must be paid to lowlands as areas of settlement and cultivation. Most of the world's people live within 1,000 feet of sea-level—highlands in general tend to be difficult to cross, severe in climate, lacking in soil where the slopes are steep, and in consequence sparsely peopled. Two kinds of lowland have been chosen for description in this and in the following chapter.

1 The nature of scarplands

The lowlands of Britain form scarpland country. Scarps are the steep edges developed by erosion at the edges of resistant rock formations (Pl. 21). Many of the readers of this book must have seen, crossed, or stood on scarps. The steep faces of the Cotswolds, the Chilterns, and the Downs are all scarps; so are the western side of Lincoln Edge and the northern slopes of the Yorkshire Wolds and the North York Moors.

Below the scarp in the picture (i.e. on the left) the ground is lower. It is based on weak rocks where erosion has cut a deep, wide vale. On the other side the ground slopes gradually away from the crest of the scarp, for the strong rocks are gently inclined in this direction. This is the ***back-slope.*** The scarp and the back-slope together form a *cuesta* (Fig. 34). The Chilterns, the Cotswolds and the other groups of hills referred to above are all cuestas. Cuestas and vales combine to make a *scarpland.*

Structure. It will be clear that scarplands are due to the erosion of gently inclined rocks where some formations are strong and some weak. The strong rocks are limestones and sandstones and the weak ones clays. Clay does not resist erosion well, for it is not cemented together; it is also impermeable—water cannot soak into the ground but must run away on the surface. Limestones and sandstones are more coherent, and water can percolate into them with the result that they are, to some extent, protected from surface wash. In a typical scarpland the formations of limestone and sandstone form cuestas, while the clays underlie the intervening vales.

Origin. The rocks of the scarplands of Britain were laid down in the sea. The sediments came from the ancient massifs in the west, and were deposited in sheets on the sea bed. A gentle upward bending of this part of the crust raised the floor of the sea and formed new land. Erosion of this land has picked out the strong and the weak formations. The former appear as belts of scarp-edged hills, the latter as lower ground.

2 River development in a scarpland

(i) *Dip streams.* When the sea floor emerged and became land rivers formed upon it. The first ones naturally flowed down the slope of the land surface, in the direction in which the rocks were inclined. These were *dip streams,* so named because the inclination of the rocks is called the dip.

(ii) *Strike streams.* As erosion made progress and the different kinds of rocks were etched into relief a second type of stream came into being. The dip streams developed tributaries along the clay belts (Fig. 35). These are *strike streams,* flowing along the strike of the rocks, i.e. at right angles to the dip.

(iii) *Scarp streams.* Water percolating into the rocks of the cuestas reappears as springs at the scarp foot (Fig. 34), feeding

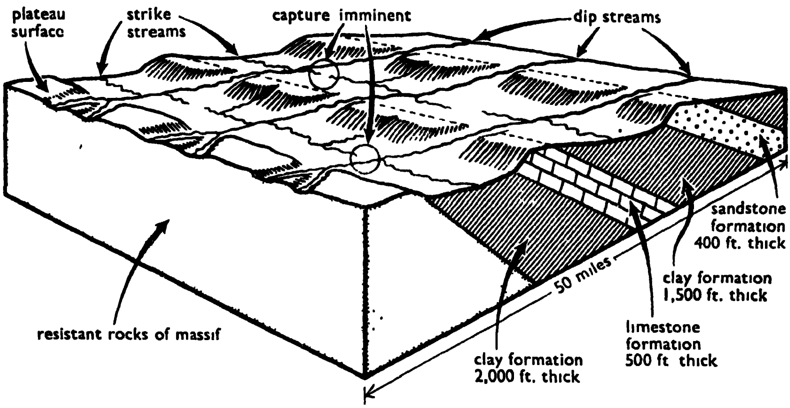
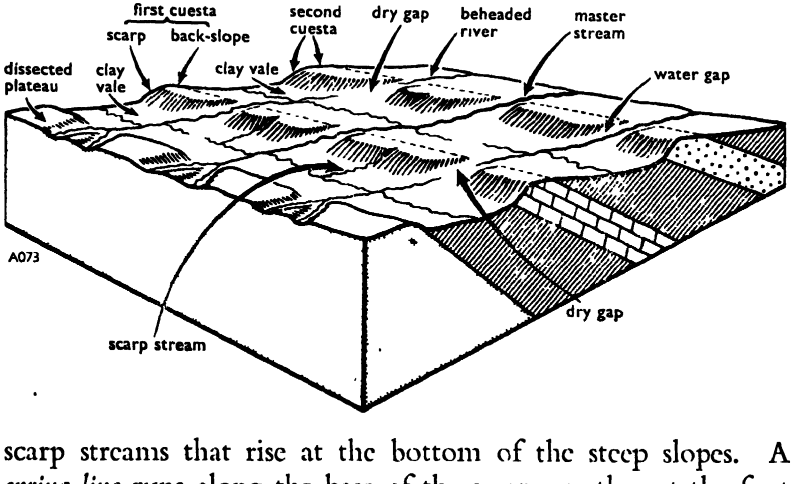


Fig. 35 THE DEVELOPMENT OF DRAINAGE IN A SCARPLAND. In the first stage (*above*) no capture has yet occurred, although strike streams are growing rapidly headward and deep vales have already been excavated in the weak rocks. In the second stage (*below*) there has been some beheading of the less powerful dip-streams, and a master stream has come into being.



scarp streams that rise at the bottom of the steep slopes. A *spring-line* runs along the base of the scarp, another at the foot of the backslope.

(iv) *Stream competition.* Rivers compete for territory. Streams with steep gradients and streams flowing over weak rocks tend to grow rapidly longer by working back at their sources, whereas those with gentle slopes and those eroding strong rocks make slower progress. Strike streams, working in weak and impermeable rocks, have a particular advantage and rapidly excavate wide vales.

(*a*) *River capture.* Now the tributaries of an especially powerful dip stream will themselves be capable of powerful erosion. For this reason certain streams grow so rapidly that they divert parts of their less powerful neighbours. *River capture* is said to occur (Fig. 35*b*). The diminished remnant of the deprived stream has been *beheaded.*

(*b*) *Gaps.* The surviving dip streams pass through cuestas by way of *water gaps,* e.g. the Guildford and Dorking gaps in the North Downs. The former route of a beheaded stream is marked by a *dry gap* (*wind gap*), e.g. the Wendover Gap in the Chilterns and the Moreton Gap in the Cotswolds.

3 Scarplands as geographical environments

(i) *Rural settlement* is often concentrated along the spring lines in strings of villages, with towns in the gaps. Spring-line sites had much to offer the early settlers—water supply, rich mixed soils along the scarp-foot suitable for ploughing, meadowland and wood on the low ground, and more wood and rough grazing on the upper scarp and the backslope. Those parts of Britain colonised by Saxon settlers are characterised by *spring-line villages* along the scarp-foot—study, for instance, an inch-to-the-mile map of the Cotswolds. Even today the backslopes remain sparsely peopled, mainly because of the lack of water. It would be a mistake, however, to think that lines of villages occur at the foot of every scarp, even in a well-settled land such as England. The Saxons were used to living in village communities and naturally established themselves in groups. Things in Kent were different. The pioneers there were Jutes, organised in families and settling in hamlets. The pattern of hamlet settlement persists in Kent to this day—one looks in vain for a belt of villages at the foot of the Kentish Downs, although the scarp and the spring-line are even better marked than in the Cotswolds. The difference is one of history not of environmental conditions.

(ii). *Towns and routeways.* Towns commanding gaps through cuestas are common in the scarplands both of England and of the Paris Basin. They are frequently called 'gap towns', a name which usefully describes their position. It should be realised, however, that many grew because they commanded routes *along the high ground* and crossing places on the rivers—e.g. Guildford. In the early days, before large-scale drainage and the building of railways, communication was often easier along the crests than along the valley bottoms.

Topics for discussion

The first four exercises should, for preference, be done in the field, but if that is impossible, O.S. or other suitable maps may be used to supply the necessary information.

1 Choose an example of a scarp and identify the scarp-forming rocks. Make a sketch of part of the scarp-face.

2 Identify a dip stream, a strike stream, and a scarp stream.

3 Draw a sketch-map to show a series of spring-line villages, marking the line or lines of springs which occur.

4 Make sketches of (*a*) a wind gap and (*b*) a water gap.

5 Draw a series of sketch-maps to illustrate the occurrence of river capture in scarpland country.

6 Choose a town which commands a gap through a cuesta, and draw a map to show the advantages of its position.

7 Use an O.S. or other suitable map of scarpland country to identify a ridgeway, and explain as fully as possible the advantages which ridgeways had over other routes in former days.

Chapter Sixteen

LOWLANDS: 2, ALLUVIAL PLAINS

SOME great rivers deposit very extensive spreads of sediment in their lower valleys. We have seen in Chapter 13 that meandering streams spread a flat bed of alluvium along their valley bottoms, but the features now to be considered are much larger than single flood plains. Where a large, sediment-laden river enters a shallow area it forms a delta at its mouth (Fig. 36). If the sea is in the form of a long inlet it tends to be filled in. The delta grows seaward and the whole basin is covered by a broad sheet of thick alluvium, becoming an *alluvial plain.*

I Great alluvial plains of the world

At the head of the Persian Gulf begins the alluvial plain of the Tigris-Euphrates valley. The common delta of these two rivers has been extending itself seaward for at least 5,000 years, as we know from the written records of the ancient cities of the plain. The inner end of the Adriatic Sea is being filled in by the Po, the Adige, and their tributaries. Behind the delta on which Venice stands lies an alluvial plain. An alluvial plain occupies the bottom of the Mississippi valley from Cairo to the sea—a distance of six hundred and fifty miles. Inland of the Hwang-ho delta in northern China is another major spread of alluvium,

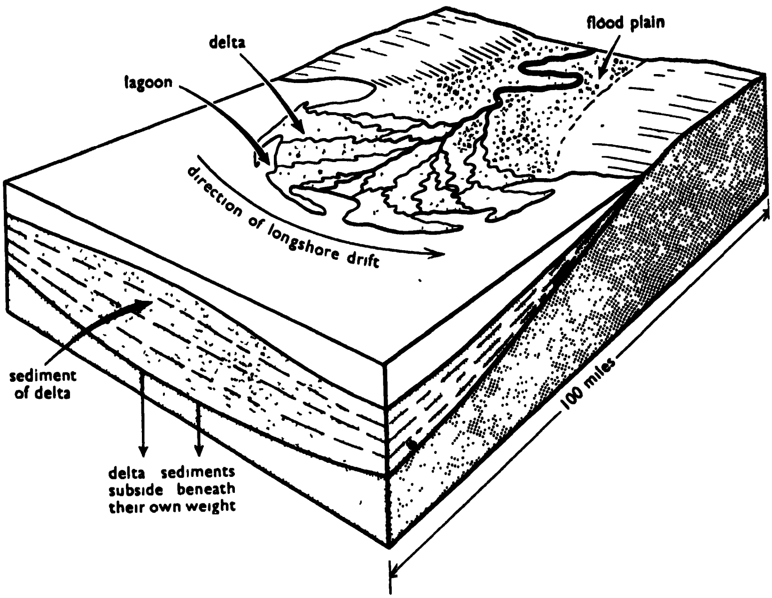


Fig. 36*a* FORM AND DEVELOPMENT of a large delta on the coast.

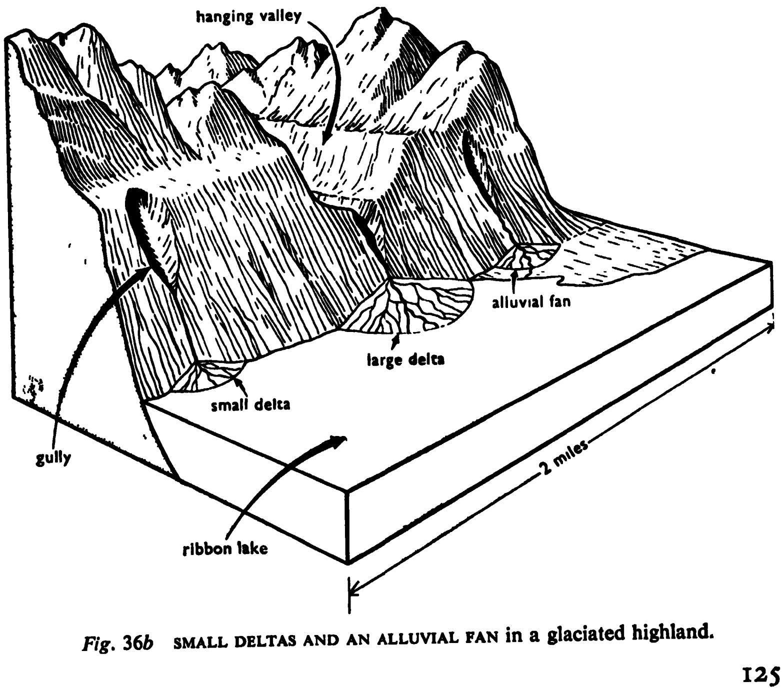


Fig. 36*b* SMALL DELTAS AND AN ALLUVIAL FAN in a glaciated highland.

while the Indo-Gangetic plain is yet a further example. Others are found in the valleys of the Nile and the Amazon (Fig. 25).

2 Formation of alluvial plains

The origin of alluvial plains is quite simple. It involves nothing more than the seaward growth of a delta, the deposition of large amounts of sediment by rivers, and perhaps also a rise of sea-level. When a river enters the sea much of its load of sediment is dropped near the shore. The solid grains of sand fall to the bottom as the speed of flow is checked, while very fine fragments and material in solution are precipitated by the sea water. That is to say, deposition is rapid near the river mouth. Sediment accumulates, and the delta is built up to, and above, sea-level (see page 136). This means that the gradient of the river above the delta is reduced. Sediment is deposited here on the banks and bed, and spread over the valley floor in time of flood. The level of the land is raised and the depth of alluvium is increased. As the process continues the whole of the valley bottom is covered with thick alluvium.

A rise of sea-level may lead to the formation of alluvial plains, by creating long shallow inlets. Deltas rapidly form in the shallow water and grow rapidly out to sea. The inlet is filled in and becomes land. The Tigris-Euphrates valley and the valley of the Nile have both been affected in this way.

3 Alluvial plains as geographical environments

The great alluvial plains have certain things in common with the flood plains of large single rivers.

(i) *Alluvium.* The plains are based on flood-laid sediment. Their soils are typically fine-grained, easy to cultivate, and in many places deep and rich. A varied mixture of rock-fragments, the addition of plant remains, and repeated flooding contribute to their depth and richness.

(ii) *Flatness.* Alluvial plains are remarkably flat, and the great rivers which traverse them have very gentle gradients. The highest points are alongside the main channels, on the natural banks known as levees (see page 106).

(iii) *High water-table.* Water is encountered in the alluvium at shallow depths : the *water-table*—the surface of saturation—stands high. In all but the rainiest climates this fact is a benefit to cultivators.

(iv) *Danger of flooding.* The natural levees are never high enough to prevent the rivers from flooding. At times of high water, when the rivers spill out of their main channels, vast areas can be inundated. In consequence the banks are artificially strengthened wherever the valley floor is cultivated.

(v) *Possibility of irrigation.* In all the examples of alluvial plains mentioned above, except that of the Amazon, the rich alluvial soils support dense farming populations. They include the richest farming country of the whole world. In addition to the natural richness of the soil, and the presence of water at shallow depths, they have the advantage that irrigation is easy. The simplest method is to inundate by flood water, controlling it, perhaps, by earth banks between fields: the centuries-old practice in Egypt provides an illustration. In parts of the Ganges valley inundation canals serve to direct flood-water to the farmland, where it is distributed by smaller channels. But if, as in the Tigris-Euphrates valley, the river floods not in the growing season but at some other time of the year, water must be raised by some means. The central parts of the valleys of the Nile, the Indus, and the Tigris-Euphrates are notable for large dams, which store water until it is needed and allow it to be released, under control, for the purpose of irrigation.

It will be observed that the three valleys just mentioned run through arid or semi-arid areas. It is there that the possibilities of irrigation and the need for it are greatest. Significantly enough, all these three valleys were the sites of flourishing cities in prehistoric times. The extremely well-watered Amazon valley, on the other hand, is still largely unexplored and unexploited.

Clearly much depends on climate as well as on the form of the ground and the nature of the rocks.

In view of their natural richness it is not surprising that alluvial plains have attracted farmers—except in the Amazon—despite the disastrous floods that happen from time to time. The land has far too much to offer for it to be left idle. By their very nature, the great alluvial plains and the smaller flood plains of innumerable single rivers are liable to be inundated. It would be impossibly expensive to prevent all floods. Consequently the people who inhabit these lowlands and who farm their soil are exposed, in the long view, to a recurrent risk.

4 River terraces

In the smaller alluvial valleys river terraces may provide safe sites for building, well drained and above flood level. A terrace is the remains of an old flood plain, now lying above the level of the river. In the valleys of the Thames and the Lea, broad spreads of gravelly and sandy terrace show where the valley bottom was when sea-level was higher : intermittent falls in the level of the sea have caused the rivers to cut down, leaving their former deposits stranded on the valley sides (Fig. 33). If the flood plain is at all marshy it is likely to be avoided by settlement, which is concentrated instead on the dry patches of terrace, where in the early days water could be had from shallow wells.

Topics for discussion

1 Choose a small local stream, and find out what kind of material it is transporting.
2 Make a map of part of an actual flood plain, showing the use to which the land is put.
3 Describe the circumstances in which a river known to you inundates its flood plain.
4 Explain why the water-table stands high in flood plains, and describe the effects of this height on settlement, referring to actual examples.
5 Use a work of reference to discover the meaning of the term *water meadow*. Give an account of the practice of irrigation in Britain.
6 Choose an example of a routeway across a flood plain. Draw a sketch-map to illustrate its course, and explain how the difficulties of the crossing have been overcome.

Chapter Seventeen

THE WORK OF THE SEA

SINCE the seas cover three-quarters of the globe no world survey can omit them. Their geographical significance has several aspects. We have already noted the effect on climate of ocean currents; the sea is the source of moisture in the air; it is well known that sea transport is cheap, so that the oceans link maritime countries together in respect of travel and trade; fisheries supply food which supplements the yield of cultivated soil; and, finally, the sea by erosion and deposition plays a great part in shaping the coastline.

The open oceans reach great depths. The deepest soundings yet have been of about 35,000 feet in the Pacific. Most of the ocean floor, however, lies between 10,000 and 17,500 feet down. It is far less regular than was formerly supposed—new techniques of sounding, by echo and radar, have revealed mountains and valleys on the ocean bottom comparable to those on the land above sea-level. Nevertheless, a useful distinction can be made between the oceans and the seas. The open ocean is deep for the most part and is not shut in by land. Seas, on the other hand, are either deep but land-locked, e.g. the Mediterranean, or shallow like the North Sea. The latter, although partly enclosed, is open on one side to the Atlantic; other seas, e.g. the Baltic, are both landlocked and shallow.

All seas are salt. The average salinity (saltiness) at the surface of the open ocean is 35 parts in 1,000—written $35^\circ/_{00}$. In dry climates the water evaporates, leaving the salt behind, and the water becomes more saline. The Dead Sea, with no outlet, has a salinity of $273^\circ/_{00}$, the eastern Mediterranean one of $40^\circ/_{00}$. The Baltic contrasts strongly with these. Receiving great amounts of fresh water from rivers, and suffering little evaporation in a cool climate, its innermost parts are scarcely salty at all, with salinities as low as $2^\circ/_{00}$. In the open oceans evaporation increases salinity near the Tropics, while heavy rainfall reduces it near the Equator. Such differences of salinity involve differences of density, which help to keep the great ocean currents on the move.

1 The continental shelf

An atlas map shows that on all sides of Britain the sea is far shallower than it is in mid-ocean. Depths are measured in dozens of feet instead of in thousands. The sea bottom in these shallow parts is a gently sloping continuation of the land, and is suitably named the *continental shelf*. The shelf results from partial submergence of the borders of the landmasses, combined with deposition of sediments carried to the sea by rivers. The North Sea, the Baltic, and Hudson Bay all lie on the continental shelf, and the Grand Banks off Newfoundland are also part of it.

The shelf extends seaward to a depth of about 450 feet, where a steeper slope leads down to the ocean floor. The width of the shelf varies greatly in different parts of the world. Along coasts bordering young fold mountains it is narrow or absent altogether, while in the China Seas and in the northern Atlantic it is unusually broad. Its geographical importance is derived from the fact that its waters are usually rich in fish. In these shallow depths light can reach the sea bed, favouring the growth of the minute animals and plants on which fish feed. Bottom-feeding fish and surface-feeders alike find the most favourable conditions of life in the shelf waters, and the great fishing grounds of the North Atlantic and its bordering seas are located on the continental shelf. The mixing that occurs in shallow water prevents stagnation, while the movement of water masses of different temperatures brings different types of fish into the grounds.

2 Tides

The tide is the rise and fall of sea-level that usually takes place twice a day. It is mainly due to the gravitational effect of the moon. The sun also raises tides, but because the sun is so far away from the Earth the moon's pull is the stronger, despite the moon's smaller size. When the lunar and solar tides coincide flood tide is high and ebb tide low—*spring tides* are experienced. When the lunar and solar tides are out of phase the tidal range is least—*neap tides* occur.

The average tidal range is greatest on the continental shelves and tidal currents are strongest there. The currents help in the mixing of waters that was mentioned above. The high tides penetrate far up inlets so that ships can make their way far inland away from exposed coasts. London has benefited from unusually high tides, while Southampton experiences prolonged high water that assists the movement of transatlantic liners. Liverpool stands on the bottle-necked Mersey estuary, which the rush of the outgoing tide helps to keep clear of silt. Tides can bring in sediment, however, instead of removing it. The rivers emptying into the Wash suffer from silting by the incoming tide. So far from being kept clear by tidal scour, the Clyde estuary would only be five feet deep at low water, if left in its natural state. Constant dredging is needed to maintain a deep channel. We see then that tides affect the life of ports by transporting sediment and by providing deep water at certain times.

Every part of the coast has its own particular tidal conditions, and each port must face its individual tidal problems. The reason for this state of affairs lies in the nature of the tides themselves. A tide is a wave, kept in motion by the gravitational pull of the moon and sun, with crests about twelve and a half hours apart. Instead of travelling in a straight line, the tidal wave is deflected by the Earth's rotation, and moves in a circle. In the English Channel and the Irish Sea there is a whole group of tidal waves, each related to a single basin enclosed by land or by shallows. It can easily be imagined that each tidal wave acts differently from all the others. Tides rise high and fall low where the size and shape of the basin increase the size of the wave, as in the Thames estuary and the Bay of Fundy. The long spells of high water at Southampton are due to the size and shape of the inlet between the Isle of Wight and the mainland. Where, on the other hand, the tidal wave is suppressed, its range may be very small—e.g. in the Mediterranean where tides are negligible.

3 Erosion and deposition by the sea

The sea is rarely still. Even weak winds raise waves that sweep across the open water and break against the land (Pl. 22). Large and strong waves can move enormous amounts of sand and shingle in a single storm. They batter to pieces the solid rocks exposed to their attack.

(i) *Wave action.* Breaking waves are the most powerful erosive agents on the shore. They cut into the land near high-water mark, as if it were being sawn through horizontally. In deep water the surface layers alone are affected by wave motion, but in shallow water near the land the movement reaches to the bottom. Friction on the bed checks the base of the wave and the top curls over and breaks. The water rushes forward up the beach as the *swash,* hurling rock fragments against the land and under-cutting cliffs (Fig. 37). By its own impetus the water is forced into crevices, compressing the air there. When the broken wave retreats as *backwash* pressure is suddenly released; the air expands, flaking off pieces of rock and so enlarging the openings.

Wear on the beach. Much wearing-down of rock occurs on the beach itself. Beach material—sand, shingle, or mud—is rolled to and fro by the swash and backwash and is pounded as waves break. The fragments are ground down, and the underlying rock surface becomes a smooth *wave-cut platform.*

Cliffs are the steep edges of the land. Undercutting by waves brings down large masses of rock, which are pounded to bits on the beach (Pl. 23). The appearance of cliffs depends on the vigour of wave attack at the base and on the nature of the rocks composing them. Strong rocks can support vertical cliffs. Lines of weakness are eroded into *caves, arches* are cut through a projection of land, and pinnacles of rock are isolated as *stacks,* but these features are merely details in the general progress of cliff retreat.

Sea cliffs in retreat show that the land is being destroyed. In places the retreat is rapid and alarming. Wave erosion, however, is slower than erosion by rivers—the rivers of Britain carry to the sea a greater quantity of rock waste than the amount removed by coast erosion from our shores. Sandy and muddy beaches consist partly of river-borne material.

Construction by waves: longshore drift. Waves can build as well as destroy, and are responsible for constructing many shoreline features. Transport and deposition by the sea are both involved.

Waves rarely come in parallel to the shore, but instead tend to approach at an angle (Fig. 38). The swash flows obliquely up the beach, whereas the backwash runs straight down. Beach material is therefore carried in a zigzag path, as the diagram shows, and moves along the shore. The movement and the moving material are both called *longshore drift.* Usually the drift is dominantly in one direction. It can be checked by groynes, which fix the beach material and protect the cliff behind (Pl. 23). Where there is an inlet longshore drift extends the beach across its mouth, forming a *spit* which is a projection of beach into open water, or a *bar* which stretches right across to the land on the far side. The water enclosed by the bar is a *lagoon* (Pl. 24).

(ii) *Smoothing of the shoreline.* As headlands are cut away by wave erosion and inlets are sealed off by bars the shoreline

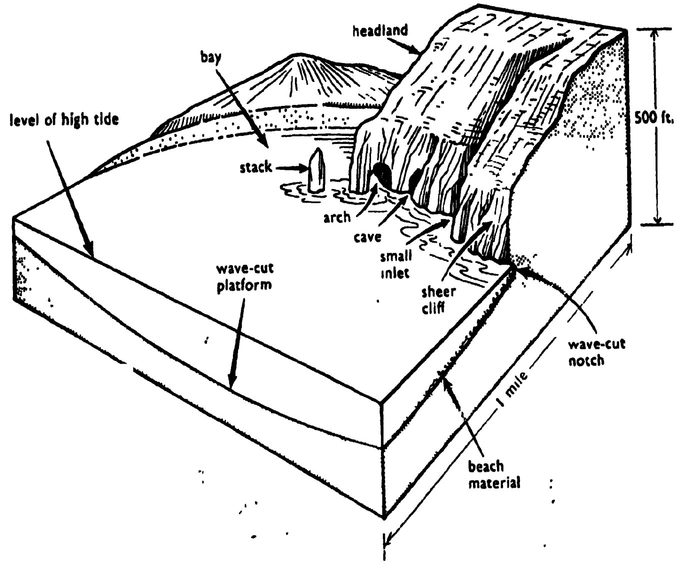
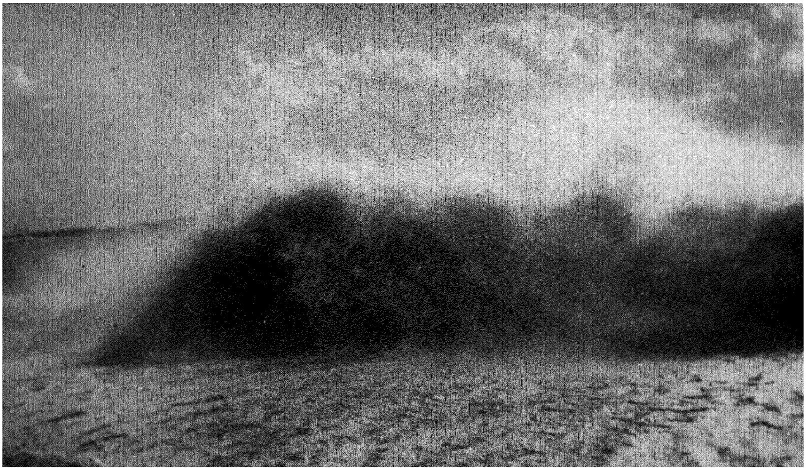


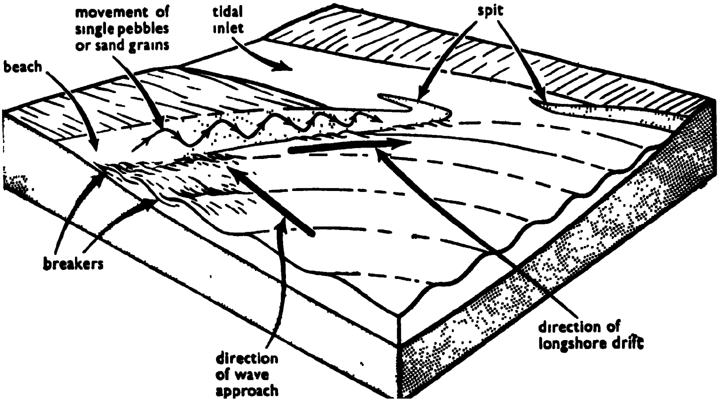
Fig. 37 FEATURES OF THE SHORELINE.

Fig. 38 (*opposite*) LONGSHORE DRIFT AND THE GROWTH OF A SPIT.

Plate 22 A WAVE BREAKING ON THE BEACH AT HOVE, SUSSEX, after a storm. The crest of the wave curves over and falls, pounding the shingle on the beach. The broken water in the foreground is the backwash of the previous wave.

Plate 23 (*opposite*) CLIFFS AT CROMER, NORFOLK. The sea is sapping the base of the cliffs, which are developed in boulder-clay. From time to time the weak rock slumps down in large masses, leaving a scar above and moving on to the beach. Wave-attack on the slumped masses begins immediately. The material broken down by the waves increases the supply of sand and shingle on the beach. The groyne has been built to arrest the transport of beach material so that the beach becomes wider and gives some protection from waves to the cliff behind.




movement of
single pebbles
or sand grains
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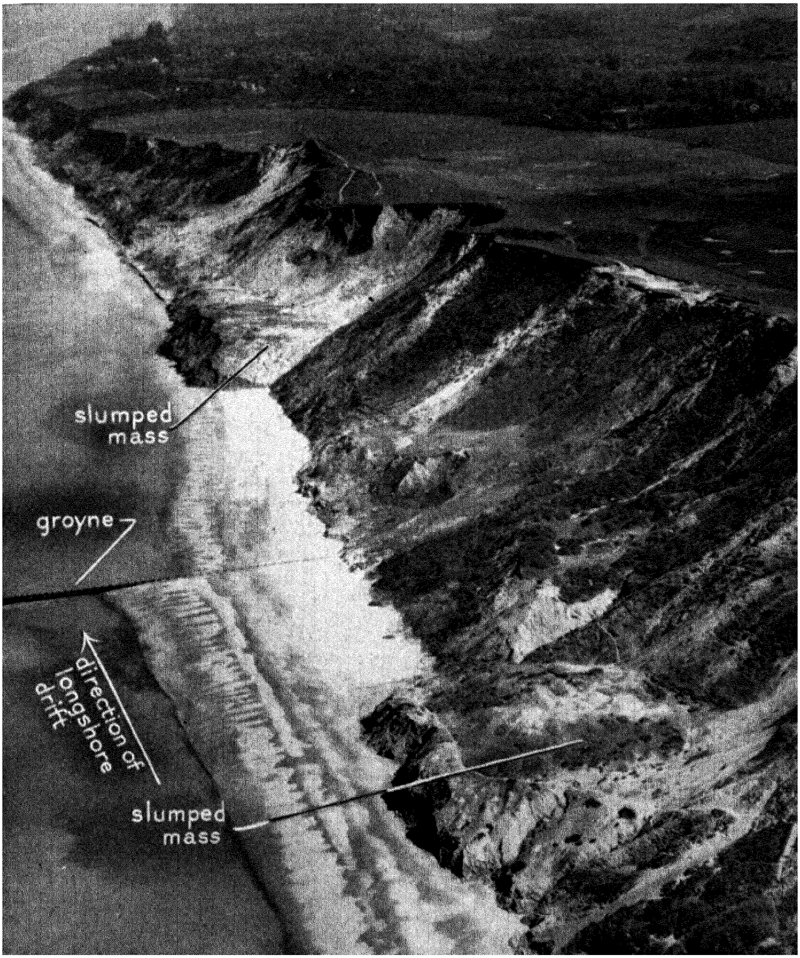
slumped
mass
groyne
direction of
longshore
drift
slumped
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Plate 24 SLAPTON SANDS, DEVON. The lagoon, about one and a half miles in length, is found in Start Bay, Devon, between Start Point and the mouth of the Dart. The beach, extending smoothly across the mouths of two small valleys, has cut them off from the sea. The lagoon thus enclosed is being filled in by beach material washed in by waves, by sediment brought in by streams, and by vegetation growing in the shallow water at the edges.

becomes smoother. Lagoons tend to disappear as time goes on, being filled by beach material washed over the bar, by the sediment of rivers, and by the remains of marsh plants.

(iii) *Seaward growth of the land.* In the long run the sea destroys more than it builds. In some places, however, the land itself grows outwards, as where large rivers bring down great loads of sediment—far more than waves and currents can remove. The feature built of silt at the mouth of a river is a *delta*—a low-lying, fan-shaped expanse of mud, marsh, swamp plants, and branching river channels (Fig. 36). The river splits into *distributaries* by breaking through its low banks of mud. Repeated splitting produces the complex net of channels typical of large deltas. All the great deltas of the world—e.g. those of the Rhine, Rhône, Nile, Ganges, Hwang-ho, and Mississippi—are affected by subsidence. So much sediment is deposited that the Earth's crust sags under its weight. If this did not happen the deltas would grow even more rapidly than they do.

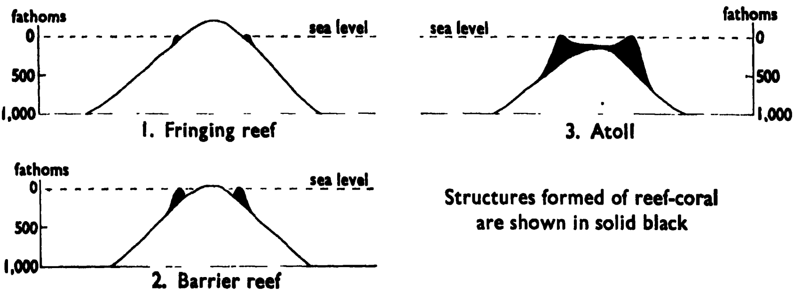


Fig. 39 THE FORMATION OF AN ATOLL.

4 Coral reefs

Corals are *polyps*—small animals similar to sea-anemones. Reef-building corals live in large colonies, where each polyp builds for itself a cup of lime (calcium carbonate). In time the mass of cups left by dead polyps is cemented by lime from other sources, and becomes reef-coral.

Reefs form in warm, shallow water. They are typical of the eastern coasts of the landmasses between 30° N. and 30° S., i.e. of the tropical and sub-tropical areas of warm ocean currents. Three main kinds of reef are distinguished :

- (i) the *fringing reef*, which borders the shore very closely
- (ii) the *barrier reef*, which lies some way from the shore
- (iii) the *atoll*, which is roughly circular or horseshoe-shaped, and forms a curved line of low coral islands standing in deep water (Fig. 39). Both barrier reefs and atolls enclose lagoons.

5 Types of shoreline

A journey of fifty miles along the coast of the English Channel reveals many contrasts in coastal scenery. Here lie cliffs and headlands, there bays biting deeply into the land. In western Scotland narrow inlets stretch far inland between rough, rocky mountains. In the Wash shallow, muddy water borders flat, low-lying country. There is endless variety of shoreline features : nevertheless, distinctive types of shoreline can be recognised, each with its typical appearance and its effect on the people of the coastal districts.

The character of the shoreline depends partly on movements in the level of land or sea. These movements have nothing to do with waves or with the rise and fall of tides. Some are due to the waxing of the great ice-sheets, which contain so much water in a frozen state that sea-level falls; when the ice-sheets wane, on the other hand, the water is released and sea-level rises. The changes are so slow that they take centuries to make themselves felt, but in the long run striking results are produced which may be described under the following heads:

(i) submergent shorelines
(ii) emergent shorelines

(i) *Submergent shorelines.* These, also called drowned shorelines, have been affected by a rise in sea-level, a sinking of the land, or

Plate 25 RANGAROA HARBOUR, AUCKLAND, NEW ZEALAND. This is the drowned shoreline of a hilly district. Before submergence the landscape had reached the stage of maturity; submergence converted its valleys into deep bays and its isolated hills into islands.

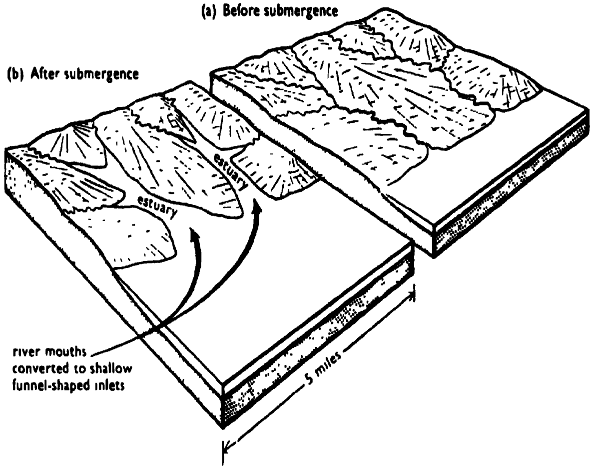


Fig. 40 EFFECTS OF SUBMERGENCE ON THE SHORELINE.

Plate 26 THE RIA OR LONG INLET, formed by the drowning of a young valley : Kinsale Harbour, County Cork, Ireland. Compare the gentle slopes of the summits and the steep sides of the rias with the corresponding features shown in Plate 19.

both. Along submergent shorelines valleys have become inlets and hills headlands. In the example shown in Plate 25 submergence has been recent—there has been very little time for wave action to perform the work of smoothing, and the shoreline remains highly irregular. It is evident that before submergence the land was very hilly.

When a lowland is partly drowned, as in eastern England, the shallow valleys are converted into funnel-shaped *estuaries* (Fig. 40). The drowned shoreline of a dissected plateau, on the other hand, is typified by deep, branching inlets called *rias*. We have seen above (page 107) that southwestern England consists of dissected plateau country ; along its shore, especially in the south, rias are numerous, for the level of the sea has risen and the lower reaches of all the young valleys have been drowned. Rias occur in similar conditions in northwestern France and in the south of Ireland (Pl. 26).

Fiords are described in the chapter on glaciation, but fiord shorelines deserve mention here because they too have been drowned. Fiords are partly submerged glacier troughs. The submergence is due partly to depression of the crust by the weight of ice—recovery from this depression is not yet complete —and partly to the great thickness of the glaciers that enabled them to erode below sea-level. As glaciers ending in the sea melted away their troughs were occupied by salt water.

The different kinds of submergent shoreline provide contrasted physical environments. Estuaries of all but the largest rivers tend to be shallow, so that ports on them lie near the sea. Rias, by contrast, are deep and offer sheltered anchorage. Before the days of large power-driven fishing vessels, numerous sailing craft were based on the rias of Devon and Cornwall, northwest France, and northwest Spain. The fishing villages stood each on its inlet. Very large rias may be used as naval anchorages—Plymouth, Brest, and Corunna are all naval bases, each standing on a huge ria. Fiord shorelines also possess deep water sheltered from the wind by high ground, but their hinterlands are usually poor and few ports develop on them. On the other hand it is easy for the farmers who cultivate the deltas along the edge of a fiord and at its head to travel by boat—on the Norwegian coast, boats, rather than land vehicles, are the commonest means of communication.

(ii) *Emergent Shorelines.* When the level of the sea falls or the land is uplifted, emergence is said to take place. During the last million years there have been, in fact, several movements of sea-level, both up and down. As parts of the crust have also moved, a piece of shoreline may have a complicated history.

Nevertheless, in some areas the signs of emergence are prominent. One of these signs is a *raised beach* now out of reach of the waves (Fig. 41). It may be associated with old cliffs, arches, caves, and stacks well above the present shore. Raised beaches are very important in the human geography of western Scotland. Here the land is rising slowly and intermittently after being relieved of the weight of the former ice cap. On the raised beaches there is soil at a low level, in country where low ground and soil are both scarce, and where climate on the hills is severe. Farmland and settlement are alike concentrated on the patches of raised beach.

A little thought will show that the rias of southwestern England are the product both of emergence and of drowning. The open plateau surfaces of the interior are related to former sea-levels hundreds of feet above the level of the present day. The deep valleys were cut by rivers when the sea stood *lower* than it does now. Then partial drowning brought the sea into the valley mouths and formed the rias as we know them today.

At the time when the sea was below its present level the Somerset plain and the Fenland area were represented by expanses of gently sloping, emerged sea bed. Because of the gentle slopes large waves broke offshore, throwing up bars of beach material (Fig. 42). The huge lagoons enclosed by the bars were filled in by mud and peat. This is the origin of the flat Fenland and of the Somerset Levels.

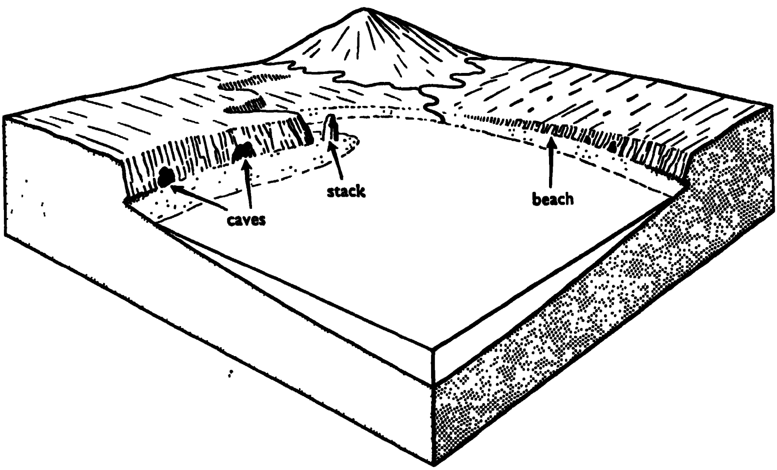
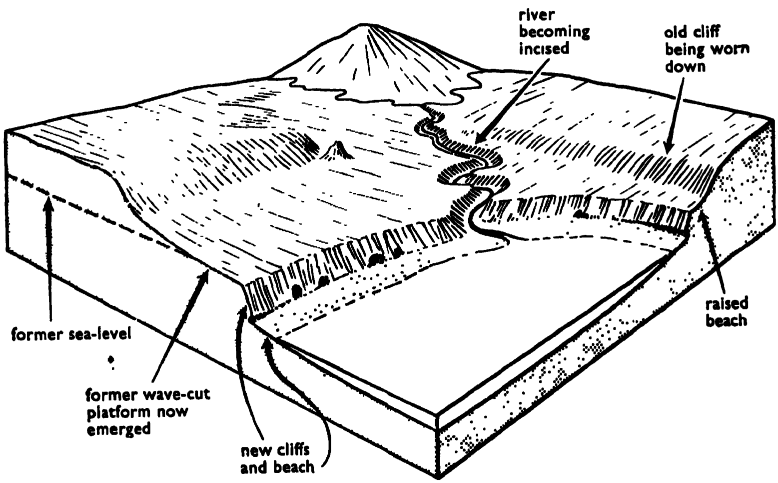


Fig. 41 A SHORELINE (*above*) before and (*below*) after emergence.



Topics for discussion

1 What is the difference between spring tides and neap tides? How is it caused?

2 Make a sketch of a piece of shoreline, identifying and naming those shoreline features which you recognise there.

3 Use an O.S. map as the basis for a sketch-map to show a piece of submergent shoreline.

4 Make a comparison between raised beaches and river terraces as sites for agriculture.

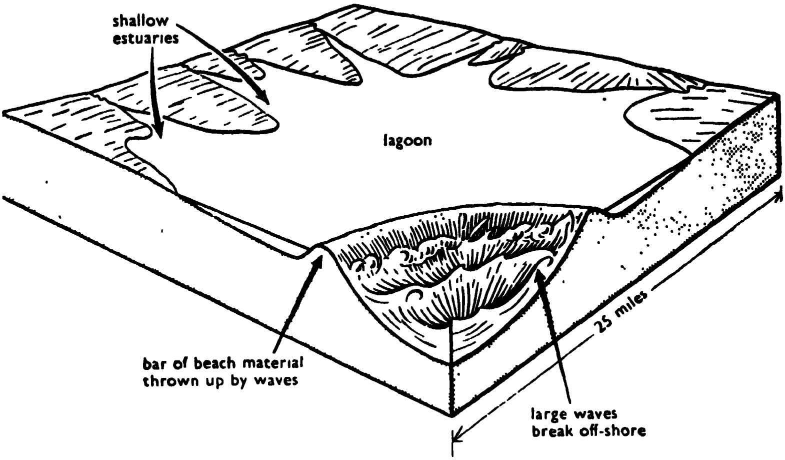
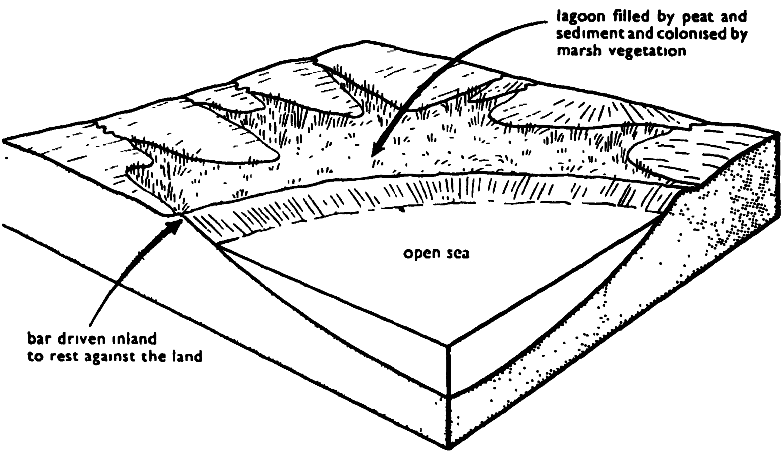


Fig. 42 FORMATION OF AN OFFSHORE BAR (*above*), and enclosure and filling of a lagoon (*below*).



5 Choose one of the fiords on the west coast of Scotland or New Zealand. Draw a sketch-map to show its physical features and the location of settlement on and near its shores.

6 Select one of the rias of southwest England and treat it similarly.

7 What kind of inlets occur on the Essex coast? Explain their origin, and draw a map to show the relation of settlement to them.

8 Referring to actual examples, discuss the use of natural inlets as harbours for shipping.

Chapter Eighteen

EROSION AND DEPOSITION BY ICE

We are still living in the Great Ice Age. The glaciers of the Alps and of the Himalayas, and the ice-caps of Greenland and Antarctica, are unusual features of the Earth's surface. Throughout most of geological time there has been little or no permanent ice upon the lands. The glaciers of the present day are due to a lowering of temperature over the whole globe. Snow can, therefore, lie throughout the year on high ground in any latitude, and also at low levels near the Poles. This cool episode has been going on for at least half a million years, and possibly for as much as a million. A million years, however, is but a small part of the Earth's history, and the effects of erosion and deposition by ice have merely been added to the results of sculpture by running water.

I Glaciated landscapes

Although the Ice Age is still with us, the glaciers and ice-caps are far smaller than they once were. Large parts of them have melted away; at the present day they are all decaying slowly. Some, indeed, have entirely disappeared, and we can see the ground over which they used to move. The landforms produced by ice erosion are exposed to view. A landscape which has been eroded by moving ice, or which has received quantities of débris from an ice sheet, is called a *glaciated landscape.* Its appearance depends largely on the forms of the land that existed before the ice came. In mountainous country tongues of ice moved down the valleys that were formerly occupied by rivers. *Valley glaciation,* or *highland glaciation,* is said to have occurred. British examples of glaciated highland country are the Lake District, the Snowdon area, and the Scottish Highlands.

Very different scenery results from the *glaciation of a lowland.* Here the work is done by an ice-sheet. In the central part, where the ice is thickest, there is much erosion and the ground is stripped of its soil and weathered rock. The interior of Labrador provides an excellent example. Near the margins of an ice-sheet the eroded material is deposited, and vast quantities of débris are left when the ice melts. East Anglia and the North German Plain, for instance, are thickly covered by the deposits of ice-sheets.

2 Valley glaciers

Valley glaciers originate at valley heads, where permanent snow is compressed into ice under its own weight. The ice cracks away from the surrounding rock, and freezing and thawing of water in the crack shatters the rock wall. Water penetrates into crevices ; when it freezes it expands and fragments of rock are wedged off.

(i) *Corries.* By the shattering of rock the valley head is enlarged into a rounded hollow called a corrie (Pl. 27). If a glacier melts completely away when the climate becomes warmer the corrie may contain in its hollow floor a shallow lake, known as a tarn.

(ii) *Frost action on the ridges.* The mountain tops above the corrie are also attacked by frost. Angular fragments of rock are wedged off, and the ridges take on a jagged appearance. Two corries working back into the same mountain develop a very sharp ridge between them. This is an *arête,* the best known examples in Britain being Striding Edge on Helvellyn and Grib Coch on Snowdon.

(iii) *Glacier trough.* A valley glacier is usually fed from several corries, corresponding to the several headstreams of a river. A thick tongue of ice moves slowly down the main valley. It is much deeper and wider than a stream of water ; because it is so slow it has to make up in volume what it lacks in speed. The bed of the glacier is the glacier trough. Like a corrie it is easy to recognise when the ice has melted. Not only is it wide and deep : it has steep sides and long straight reaches, for a glacier cannot easily flow round sharp bends. Many spurs in the original river valley are cut away by the ice (Pls. 1, 17, 28).

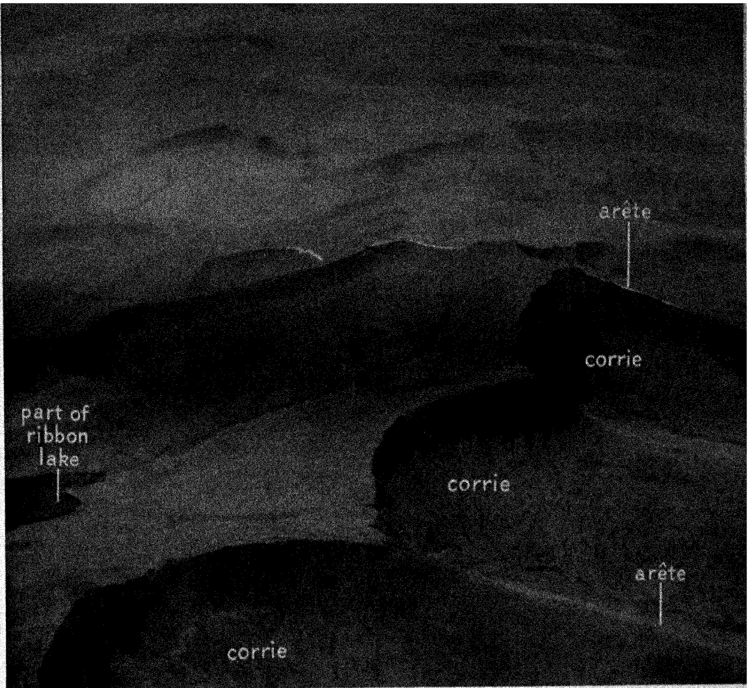
(iv) *Ribbon lakes.* In many glacier troughs there are long, deep lakes, such as those of the Lake District and the fresh-water lochs of Scotland. These too are the work of ice. A valley glacier, heavily charged with broken fragments of rock, acts like a gigantic rasp. Being so thick it can excavate hollows in its bed. After the disappearance of the ice these long, narrow basins are filled with the waters of ribbon lakes (Pl. 17).

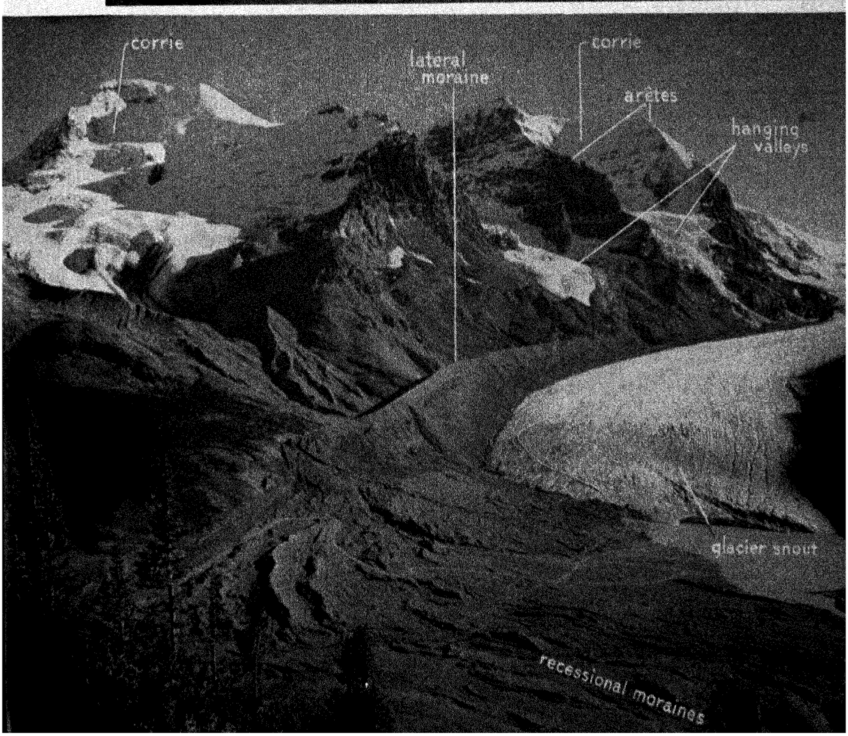
(v) *Hanging valleys.* Another common feature of a glacier trough is the hanging valley. This is a tributary valley which enters the main trough above the level of the floor. A hanging valley is no more than the trough of a tributary glacier. The main glacier needs a deeper bed, and since the two streams of ice meet at the same surface level the tributary trough is shallow by comparison with the main one. In Plate 28 two hanging valleys are easily discernible. The glaciers in them have not yet entirely vanished, but it is quite clear that the tributary troughs hang high above the floor of the main valley.

(vi) *Glaciated rock-knobs.* In many glacier troughs can be seen

Plate 27 (*opposite, top*) CORRIES IN THE BRECON BEACONS, CENTRAL WALES. The corries are former valley-heads deepened and enlarged by the heads of glaciers, while the arêtes are divides sharpened by glacial action into steep ridges.

Plate 28 (*opposite, bottom*) GLACIAL FEATURES IN THE NEIGHBOURHOOD OF MOUNT ATHABASCA, ALBERTA, CANADA. The Columbia Glacier reaches its termination on the right of the view. This glacier has melted considerably in recent times, leaving its moraines standing beyond the ice-edge. The three smaller glaciers on the left no longer unite with the main glacier, but melt away at the mouths of their tributary valleys.


arête
corrie
part of
ribbon
lake
corrie
arête
corrie


corrie
lateral
moraine
corrie
arêtes
hanging
valleys
glacier snout
recessional moraines

upstanding knobs of rock, which have been scoured on one side and plucked on the other. The scoured side, facing *up* the glacier, was smoothed by ice charged with particles of rock. The plucked side, facing *down* the glacier, had blocks pulled away as the ice moved onwards. The term *roche moutonnée* is often used for a feature of this kind.

(vii) *Moraine.* Nothing has yet been said about deposition by valley glaciers. It is clear that deposition must occur, for the eroded and broken rock removed from ice-worn highlands must be laid down somewhere. Now a valley glacier can extend well below the snowline before it melts, but as it is moving into regions of warmer and warmer air it is bound to melt at some point—the glacier snout (Pl. 28). Here the broken rock tends to accumulate.

The material carried by ice is called moraine. In Plate 28 large mounds of moraine near the glacier snout show that at one time the ice was more extensive than it now is. The glacier is said to be in retreat. The farthest point ever reached by a valley glacier is likely to be marked by a mound of rubble—the terminal moraine. As the ice melts back by stages, recessional moraines are formed where the snout is stationary for a time.

(viii) *Scree and alluvium.* Frost still attacks the crests and summits, even after the valley glacier has entirely vanished. Loose fragments of jagged rock fall down the mountainside, and in places pile up as banks of scree.

Some troughs have very flat floors. The irregular rocky bottom lies buried under thick alluvium—pebbles, sand, and silt. Some of this débris is brought down by the stream of meltwater from the glacier snout, and more is transported by the ordinary river in later times.

(ix) *Fans and deltas.* Valley glaciation provides much loose débris and many steep slopes. When rivers begin to flow again they are likely to be swift in some reaches and heavily loaded with fragments of rock. Their load is deposited where their speed is checked, especially where they reach the bottom of a large trough. The sediment forms deltas where the streams flow into lakes, and alluvial fans where they come down to land instead of to water (Pl. 17). The largest fans and deltas occur beneath the mouths of large hanging valleys (Fig. 36*b*). It is possible for a delta to grow right across a lake from the side, dividing it into two ; Buttermere and Crummock Water in the Lake District have been separated in this way.

In the geography of a glaciated highland deltas and fans are noteworthy features. In middle latitudes, for instance in Scotland and in Norway, the high ground is likely to be useless for cultivation because of its severe climate and lack of soil. Parts of the trough floors are marshy, other parts are submerged by ribbon lakes. The fans and deltas on the other hand are naturally well drained and their soil is thick. Many have cultivated fields on them, with a farmstead near the apex.

(x) *Glaciated shorelines.* A glacier trough which runs down to the sea and has salt water in its lower end is a *fiord.* The deep and steep-sided inlets of Norway and the sea-lochs of Scotland are all fiords. Fiords are also found in British Columbia and Alaska, in southern Chile, and on the west of South Island, New Zealand. Where glaciers still reach the sea, as they do in many parts of Greenland, large masses of ice break off from time to time and float away as icebergs.

3 Ice-sheets

Although we are still in the Great Ice Age, we are living in one of the more genial intervals. When the cold was at its height ice-sheets covered large areas of land, in regions that are now thickly settled and intensely farmed. Most of Britain and northern Europe lay beneath the ice-sheet. In North America there were equally large caps, which covered the whole of the north and extended as far south as the confluence of the Mississippi and the Missouri. In the centres of the sheets there was probably a thickness of two miles of ice. Snowfall kept up the supply, and the ice moved outwards under its own weight, slowly but with immense power.

4 Erosion by an ice-sheet

(i) *In the central area* erosion by ice was dominant. Leading examples of this kind of country include Finland and Canada (Pl. 18). Now that the ice no longer covers the countryside a landscape is revealed consisting of innumerable rock-knobs and lake basins. In the general view the relief looks subdued, but it is very irregular in detail. The pattern of drainage is extremely confused. There is much bare rock, swept clear and scoured by ice. Farming is scarcely possible in many areas because of the lack of soil, and the climate at the present day is still severe in winter. The search for minerals, however, is made easier by the bareness of the rock.

(ii) *Through valleys* are carved where ice is hemmed in by high ground. It spills through the passes and wears them down. This process is operating now round the edge of Greenland, and formerly went on also in Scotland. There thick ice over the centre of the Highlands found outlets to the west, and cut deep troughs that go right through the mountains (Pl. 17). Conditions were similar in Scandinavia. The ice was deepest over the northern Baltic, and overflowed westwards through gaps in the mountains. These gaps were straightened, widened, deepened, and now form passes between the Norwegian and Swedish sides of the watershed.

5 Deposition by an ice-sheet

(i) *Moraines.* The huge bulk of material removed by an ice-sheet from the central areas is laid down at and near the margins. Ice-caps, like valley glaciers, leave bands of terminal moraine at their outer limits, and recessional moraines as they decay. In Denmark and northern Germany the moraines survive as belts of low, uneven hills. Those of lowland Britain have been much eroded and are difficult to identify, but one especially interesting example may be given. It is the terminal moraine at Finchley, in north London, where one lobe of an ice-sheet remained stationary for a time. The load of rock fragments melted out

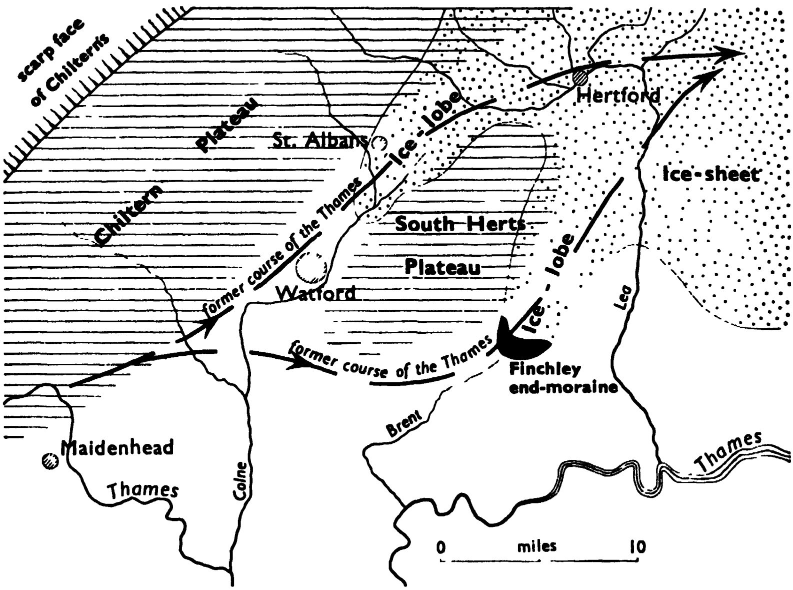


Fig. 43 THE DIVERSION OF THE THAMES BY ICE.

at the ice edge, and now forms the most southerly terminal moraine that has been discovered in this country (Fig. 43).

(ii) *Boulder-clay.* Between the eroded central area and the belt of moraine at the edge, an ice-sheet deposits boulder-clay. This is clay composed of the fine rock particles transported by the ice, together with stones of various sizes. Part of it is laid down by the very stony and dirty ice at the bottom of the sheet, the rest when final melting takes place. The nature and appearance of a spread of boulder-clay depend on two things—the kind of country over which the ice advanced, and the age of the deposit. In East Anglia boulder-clay reaches thicknesses of three hundred feet, and covers hundreds of square miles. It was brought by ice that had passed over Chalk country, and therefore contained pebbles and fine grains of chalky débris. It is suitably named Chalky Boulder-Clay. The soil developed on it is naturally rich in lime, and a great deal of the boulder-clay country is under the plough. As glacial deposits go, this one is rather old. It forms a somewhat featureless landscape.

(iii) *Drumlins.* In other parts of the country the clay is newer

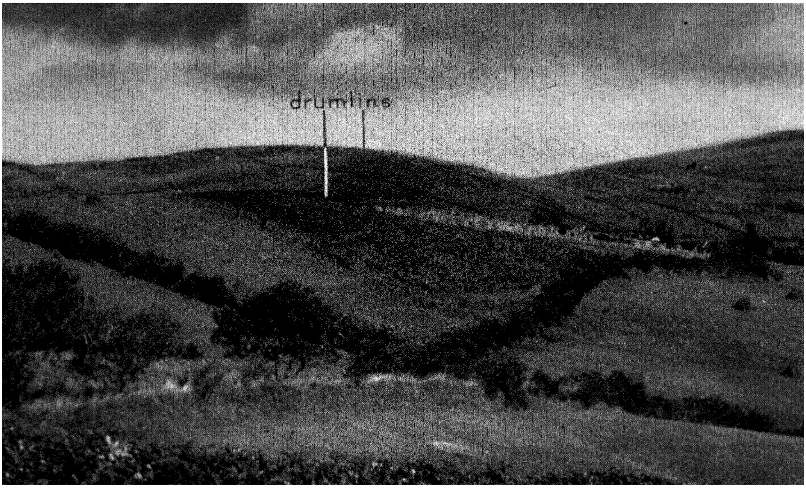


Plate 29 DRUMLINS NEAR DONEGAL, NORTHWESTERN IRELAND. These smoothly moulded hills rise to a height of some 200 feet and are about half a mile in length. They are but a few of the hundreds in a single swarm.

and has been less eroded. The shapes into which the ice moulded it are still visible. In northeastern Ireland, Anglesey, and the Eden valley, among other places, the boulder-clay forms drumlins. These are low rounded hills, oval in plan (Pl. 29). Surface drainage on drumlins is good, but the hollows between them are liable to be enclosed, waterlogged, and marshy. Settlements and farmland are concentrated on the drumlins, while many of the hollows are filled with peat bog.

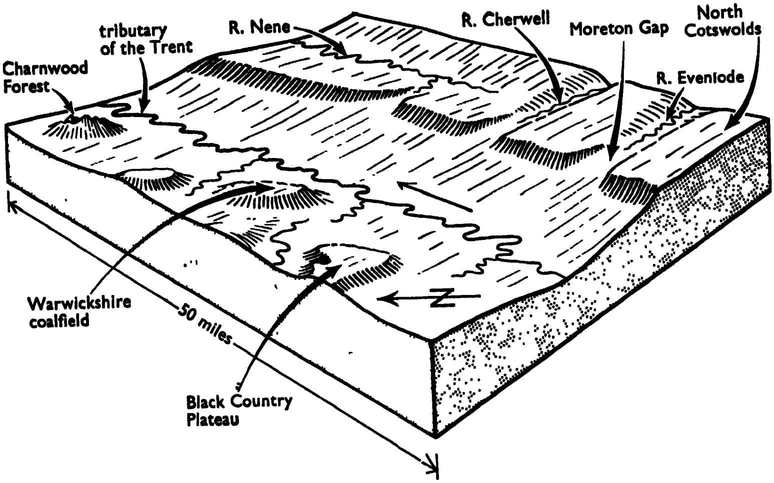
(iv) *Sands and gravels.* Just as meltwater carries away débris from the snout of a valley glacier, so streams transport material from the front of an ice-sheet. Much of it is sand and gravel, and the whole is called *outwash.* On the mainland of Europe there are wide expanses of outwash beyond the belts of moraine. The extensive heathlands of northwestern Germany and of northern Holland are based on outwash, as is the sandy country of western Denmark. Outwash deposits are usually coarse-grained and permeable; water percolates freely through them, dissolving and carrying away the soluble material and developing acid soils. Outwash sands and gravels occur in Britain in many valleys north of the Thames. Some have been re-sorted by rivers, but others remain as they were originally laid down. They are much worked for sand and for concrete aggregate.

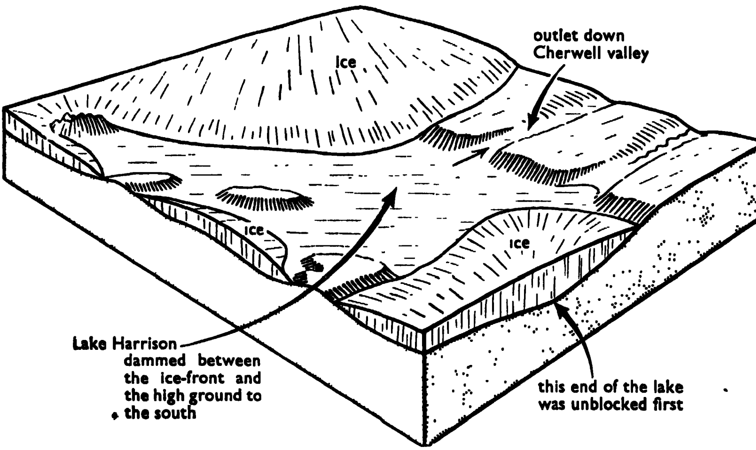
(v) *Loess.* Loess is a fine wind-borne silt. It is free from stones and physically easy to cultivate. In Europe during the height of the Ice Age a great deal of loess was deposited by violent winds, for the climate was stormy and large quantities of loose material could be picked up from the sheets of outwash or from the seashore. Loess can only form in a fairly dry climate. There is little in Britain, but on the mainland of Europe a broad belt of it runs westwards from the Russian grasslands. It becomes patchy in the Danube basin, but persists into the Rhine valley and along the northern flanks of the highlands of central Germany. There is more of it along the southern coast of the Channel. Wind-borne dust did reach southeastern England, but the wetter climate there led to the formation of brickearth, as in the valleys of the Thames and the Lea.

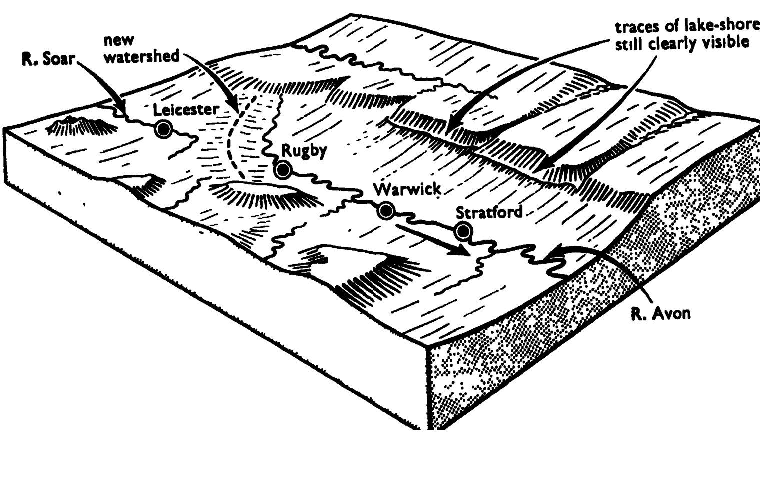
It is often thought that both brickearth and loess are naturally fertile. This is not always so. Their value in farming depends partly on the kind of soil that has developed on them. In the Russian grasslands the loess was colonised by annual grasses. For centuries the ground was enriched by dead plant material, for there was little rain and the dissolving action of water was not severe. The resulting soil—blackearth (also called by its Russian name chernozem), is rich both in lime and in humus. But farther westwards, in areas of wetter climates, the loess soils are poorer. Just because they are naturally poor they cannot support thick forest. The earliest farmers, therefore, chose the loess areas, cultivating their plots for a few years and then shifting to a fresh locality.

However, the soils both of loess and of brickearth respond well when fertilisers are applied. Where it has paid to enrich them they are notably productive, as can be seen from the market gardens on the brickearth of the London Basin and the intensive farming on the loess (*limon*) of northern France.

(vi) *Ice-sheets and the drainage pattern.* It can readily be imagined that the great ice-sheets, advancing across lowlands and belts of hills and depositing boulder-clay and outwash, disturbed the


Charnwood Forest
tributary of the Trent
R. Nene
R. Cherwell
Moreton Gap
North Cotswolds
R. Evenlode
Warwickshire coalfield
50 miles
Black Country Plateau


ice
outlet down Cherwell valley
ice
ice
Lake Harrison dammed between the ice-front and the high ground to the south
this end of the lake was unblocked first


R. Soar
new watershed
traces of lake-shore still clearly visible
Leicester
Rugby
Warwick
Stratford
R. Avon

network of streams. In northern Germany the land slopes generally from south to north, and the main rivers would be expected to flow northwards. However, they have rather angular courses. They were obstructed when the Scandinavian ice-sheet spread southwards, and had to find outlets along the ice edge. In places the diverted courses are retained.

Many lakes formed in river valleys blocked by ice. One very large lake, Lake Harrison, was dammed in by ice in the English Midlands (Fig. 44). Before the ice arrived there was no river Avon, but instead the area was drained by a stream flowing to the northeast. Then came the damming up of the valley and the formation of Lake Harrison. When the ice began to melt an outlet appeared at the southwestern end. The outlet stream has persisted ever since, extending itself headwards to form the Avon that we see today.

(vii) *Summary of the geographical effects of sheet glaciers.* It will be seen from the foregoing paragraphs that the deposits of an ice-sheet and its erosive effects are very varied. However, the effects of sheet glaciation on the quality of land may be fairly summarised as follows:

- (*a*) in the central area soil is removed
- (*b*) in the surrounding belt boulder-clay is deposited. It often develops productive soil because it is a mixture of different kinds of rock particles
- (*c*) the terminal and recessional moraines are often of coarse material, and are then of little use for agriculture
- (*d*) outwash deposits develop acid soils, in the natural state often under heath; they can be planted with conifers
- (*e*) loess and brickearth soils yield well if well fertilised
- (*f*) sheet glaciation disorganises pre-glacial drainage

Fig. 44 (*opposite*) GLACIER LAKE HARRISON AND THE ORIGIN OF THE WARWICKSHIRE AVON. (*top*) The landscape in immediately pre-glacial times, with a large tributary of the Trent flowing to the northeast in front of the Cotswold-Northamptonshire scarp. (*middle*) Advance of the ice and impounding of the lake. (*bottom*) The landscape of today, with the Avon flowing to the southwest, roughly on the line of the old tributary of the Trent. Drainage has been reversed.

(*g*) growth and decay of ice-sheets are associated with falls and rises of sea-level

6 Hydro-electric power

The lake basins of a glaciated highland or of the central area of a former ice-sheet provide natural reservoirs. Many of them are used in hydro-electric schemes which are also assisted by the numerous waterfalls. Ribbon lakes in Scotland and North Wales have their levels raised and controlled by dams across the deep, narrow valleys. Large generating stations in the St. Lawrence valley of Canada use water from the complex net of lakes and streams on the glaciated Laurentian Shield, and take advantage of the fall of water over the edge of the plateau. Norway, Sweden, Switzerland, Austria, and northern Italy, all with little or no coal, have greatly developed their resources of water power in glaciated highland areas. It is significant that former glaciated highlands are still likely to have heavy rainfall at the present day, and to experience little evaporation. Thus advantages of climate are added to those of landscape.

Topics for discussion

1 Use an O.S. or other suitable map for the basis of a sketch-map to show a piece of glaciated highland.

2 Examine carefully O.S. maps of glaciated highland, in order to locate through valleys. Find one which carries a road and draw a sketch-map of it.

3 Explain why in glaciated highlands parts of the surface consist of bare rock, while elsewhere there are large accumulations of débris.

4 Using an O.S. map as a basis, draw a sketch-map of drumlin country, inserting roads and settlements.

5 Explain why a drumlin field may be easier to cultivate than a flat spread of boulder-clay.

6 In parts of the English lowlands, outwash material is extensively quarried. What is it used for, and why is its occurrence advantageous ?

7 Locate on a sketch-map any one of the hydro-electric schemes of a large area, e.g. Scotland, indicating the position of the dams and reservoirs.

Chapter Nineteen

LANDSCAPES IN DRY CLIMATES

An arid climate has been defined in Chapter 6 as one in which all the rain that falls can be evaporated. Its leading characteristic is dryness : wide expanses of the land are bare ; a strong sun beats down on the naked ground from a sky free from cloud ; rainfall is rare, and when it occurs it comes in thunderstorms and is soon over.

1 Weathering in arid climates

The sun warms the surface of the bare rock during the day, while by night cooling by radiation is rapid. Heat escapes through the clear sky. There is a large daily range of temperature in the desert air, especially near the ground.

The marked and rapid heating and cooling of the bare rock cause it to break up. Two processes are at work. Heat penetrates the rock very slowly, and the outer surface is, therefore, warmer than the inside during the day. Heat makes rock expand, and the outer skin splits off as flakes and angular slabs. In the foreground of Plate 34 the upstanding rock has a scaly appearance, because of the splitting away of large fragments. Sometimes the slabs are so numerous that they pile up as banks of scree, similar to those of cold mountainous areas where the rock is shattered by frost.

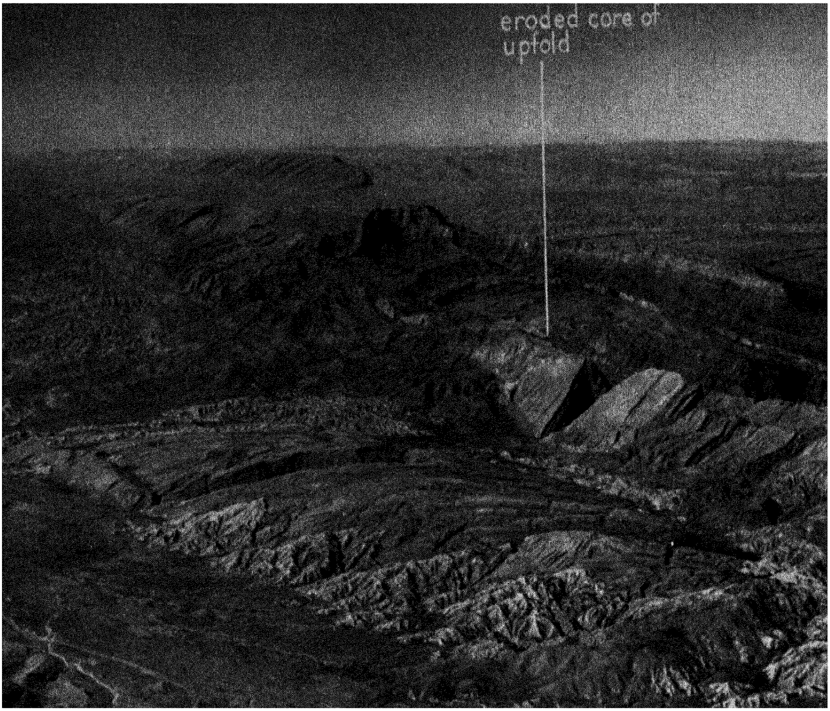


Plate 30 ROCK DESERT IN PERSIA. Note how the upfold which runs obliquely across the view from left to right is clearly displayed. There is very little soil, and large areas are quite soil-less. Strong rocks stand up clearly in relief, and the relatively weak rocks in the core of the upfold have been severely eroded.

In arid climates, however, a second process continues the work of rock-breaking. Very many rocks are composed of grains, either crystals or small particles such as those in sandstone. Different grains expand and contract at different rates and by different amounts. The daily heating and cooling, by causing this alternate expansion and contraction, make the rock fall apart. The firm rock has become sand.

2 Action of the wind

At this point the wind comes into action. Since there is little vegetation to bind the loose material it can be moved freely whenever the wind blows.

Rock deserts. Parts of the desert are kept free from sand, for the wind blows it away as rapidly as it forms. This is the origin of rock deserts, one of which is illustrated in Plate 30.

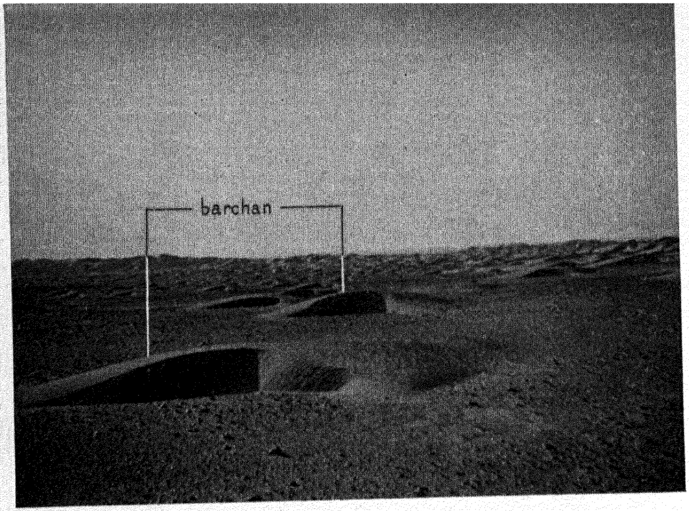
Notice how the bare bones of the landscape show at the surface; the structure of the rocks is clearly revealed.

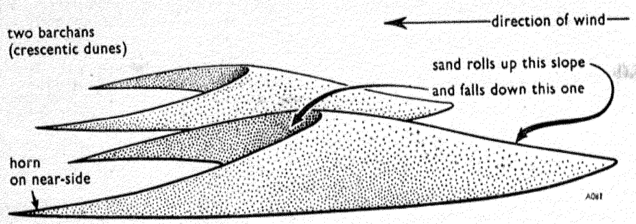
Gravel deserts occur where the ground is covered by pieces of broken rock too large for the wind to move.

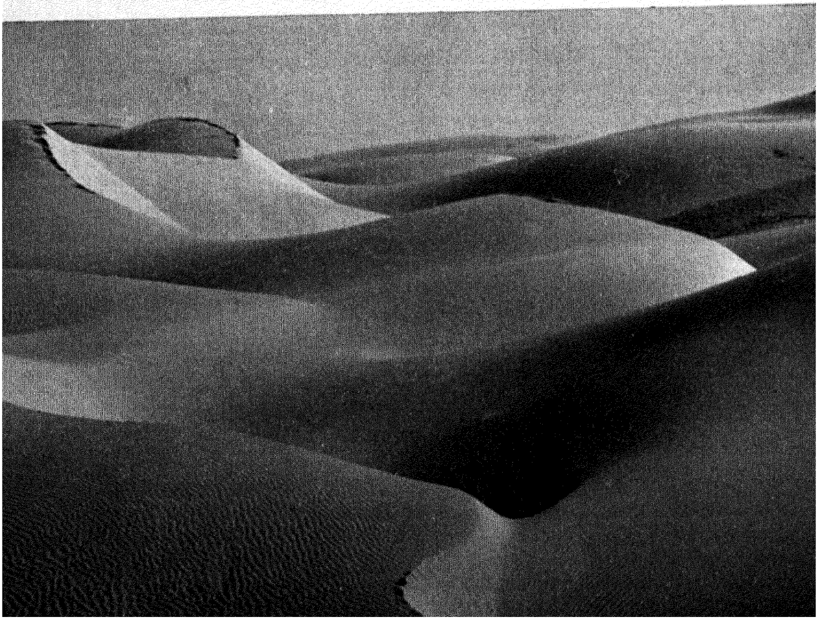
Sand deserts are found where the wind brings and deposits sand. If sand is abundant it forms a *sand sea*, for it is shaped into large waves by the wind. It is important to remember that only about a quarter of the desert lands of the world are sandy—the remainder are floored with bare rock or with gravel. A single sandhill is a *dune*. A common form is the crescentic dune or *barchan* (Fig. 45; Pls. 31, 32). It has two horns that point down-wind, while on the windward side there is a comparatively gentle slope, up which the sand grains roll. In the Sahara another kind of dune, the *seif dune*, forms a long ridge parallel to the direction of dominant winds. The long hollows between seif dunes are used as routes by desert caravans.

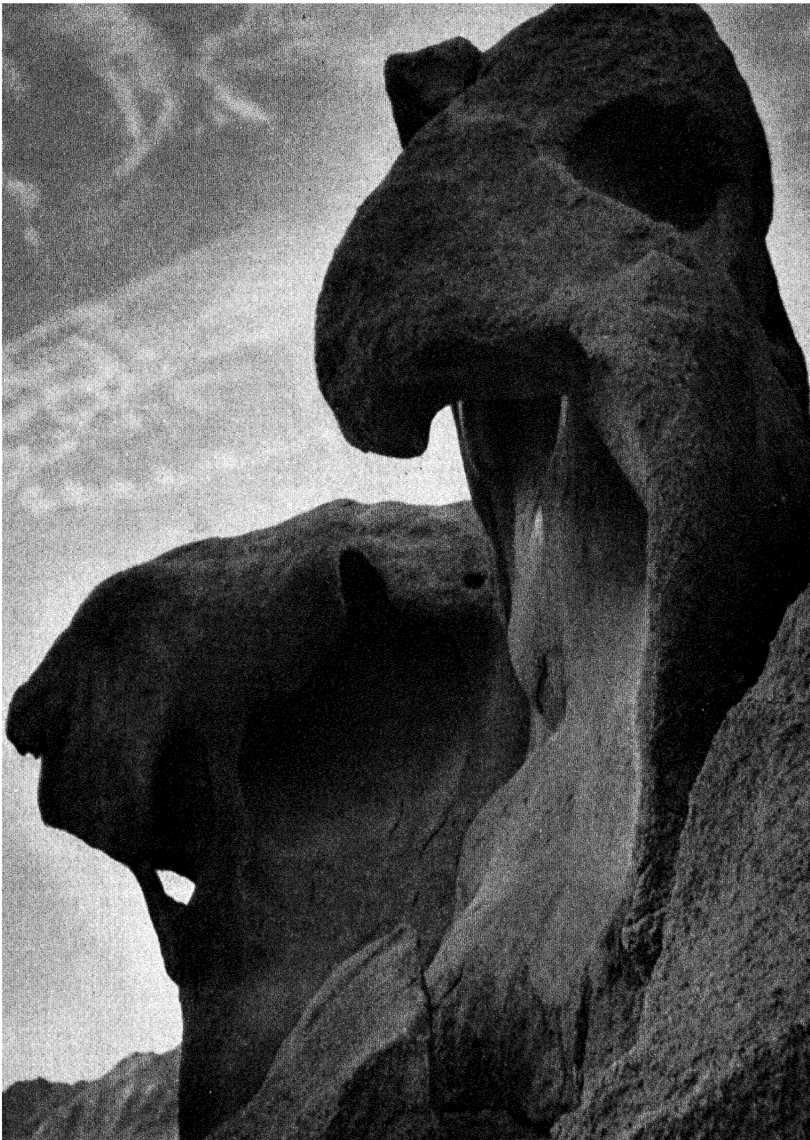
The sand-blast. The desert wind, armed with sand, is a most effective agent of erosion. The sand is hurled against exposed rock. All the lines of weakness are delicately picked out, and many fantastic shapes are carved (Pl. 33). The effect is rather like that of waves on the sea shore: wind erosion can cut arches and caves, or leave pinnacles of rock like the stacks of coastal scenery. There is another resemblance, too—just as wave action attacks cliffs at the base, so does wind erosion in the desert undercut upstanding rock masses. The wind's load of sand is concentrated near the ground, and the action of the natural sand-blast is, therefore, greatest at low levels. Pedestals and mushroom-shaped rocks result from undercutting.

Export of sand. Wind can carry sand uphill, and can even take it over mountains far beyond the limits of the desert. Some sand is blown off the Sahara and across the Mediterranean, colouring the 'blood rains' of southern Italy, and grains of Saharan sand sometimes fall on Swiss glaciers. But the greatest export of sand occurs in eastern Asia. Dust from the Gobi


barchan


direction of wind
two barchans
(crescentic dunes)
sand rolls up this slope
and falls down this one
horn
on near-side





background and in more detail in Plate 32. Fig. 45 shows how barchans are formed.

Plate 32 (*opposite*, *bottom*) DESERT DUNES. These dunes form part of a sand sea, where the whole of the surface of the ground is covered by loose sand which the wind heaps into huge waves. In the picture the dunes are moving from left to right —notice the steep slopes on the right-hand faces of the dunes, where the sand falls down over the crests. Apart from these steep faces, the sand is formed into ripples similar to those produced by water on the foreshore.

Plate 33 (*above*) SANDBLASTED ROCKS IN THE SINAI DESERT. The weird shapes are due to abrasion by wind-blown sand ; in this arid region there is no vegetation to fix loose rock-waste, and clouds of sharp sand-grains are moved by every wind that blows. Every line and point of weakness in the solid rock is revealed by erosion.

Desert is blown away by the winter monsoon and carried into the Hwang-ho basin. It blankets the area where it falls with sheets of loess hundreds of feet thick.

In the area of deposition the valley bottoms are filled with loess, and hills rise like islands from the sea. Rivers flow in narrow canyons, while roads and tracks run in trenches worn by the feet of men and animals, the wheels of vehicles, and by rainwater. The enormous quantities of sediment which the Hwang-ho carries down from the loess belt have earned it the name *Yellow River*. Part of the sediment is spread on the valley floor as alluvium by the annual floods, and part goes to extend the huge delta. The loessic alluvium is a great benefit to agriculture in the lower Hwang-ho basin, but the sediment tends to choke the channel, to make the river change its course, and to increase the danger of disastrous flooding.

3 The work of water in deserts

It seems strange to speak of water in arid climates. Few desert areas, however, are entirely without rain. Round the desert margins thunderstorms break out from time to time, and although they are infrequent they can be severe. In the desert air there is much heat energy available, and inches of rain can fall in a single storm.

When rain does come, running water can erode powerfully. The ground has little protection by plants, and there is plenty of rock waste for the water to transport. High ground bordering a desert is usually gashed by deep gullies, which are streamless for most of the time, but which carry destructive torrents after rain falls. These streams are short-lived, vanishing as their water evaporates or sinks into the ground. Their large loads of sediment form alluvial fans where the valleys open on to lower ground.

Sometimes there is enough water to form a lake in the bottom of a desert basin. Desert lakes are salt, and many of them dry up from time to time, leaving salt deposits encrusting the surface of the ground.

4 Deserts as barriers

It is easy to imagine that arid regions are barriers to the movement of man. They are scarcely habitable, except where water occurs in oases (see pages 44–46). For many centuries they have been avoided, and have separated populous areas on each side. It was the great belt of desert connecting the Sahara to the Gobi that isolated Europe from China in the Middle Ages, while the Sahara itself largely cut off the Mediterranean lands from the big cities of central Africa. Apart from the physical problems of travel and of water supply, the inhabitants of the deserts were themselves an obstacle to communication. It is hard to enforce the rule of law in a thinly peopled and arid region. Desert dwellers tend to be left to themselves, and many of them still regard travellers through the desert as fair game.

In recent times portions of the Old World deserts have become more or less well policed. Land transport is both safer and quicker than it used to be—there are bus services across the Sahara and in the Middle Eastern desert. But the strongest influences are those of the aeroplane and of the demand for oil. While it may be impossible—or at least very difficult—to construct and maintain roads and railways, it is simple enough to fly across the desert. The problem of living in arid climates has been partly solved by the oil companies working in the Middle East, who can afford to construct air-conditioned buildings and to replace camel transport by powerful vehicles. Nevertheless, life in the desert remains anything but pleasant for those accustomed to cooler and more humid regions.

5 The landscape of semi-arid regions

In semi-arid climates the power of the various agencies that shape the land is modified. There is more rain than in arid climates. Thunderstorms are still typical and still heavy, but are more frequent than in the deserts. Because there is more water there is more vegetation, but the cover may still be thin. Wind erosion is less effective than in truly arid conditions, for the

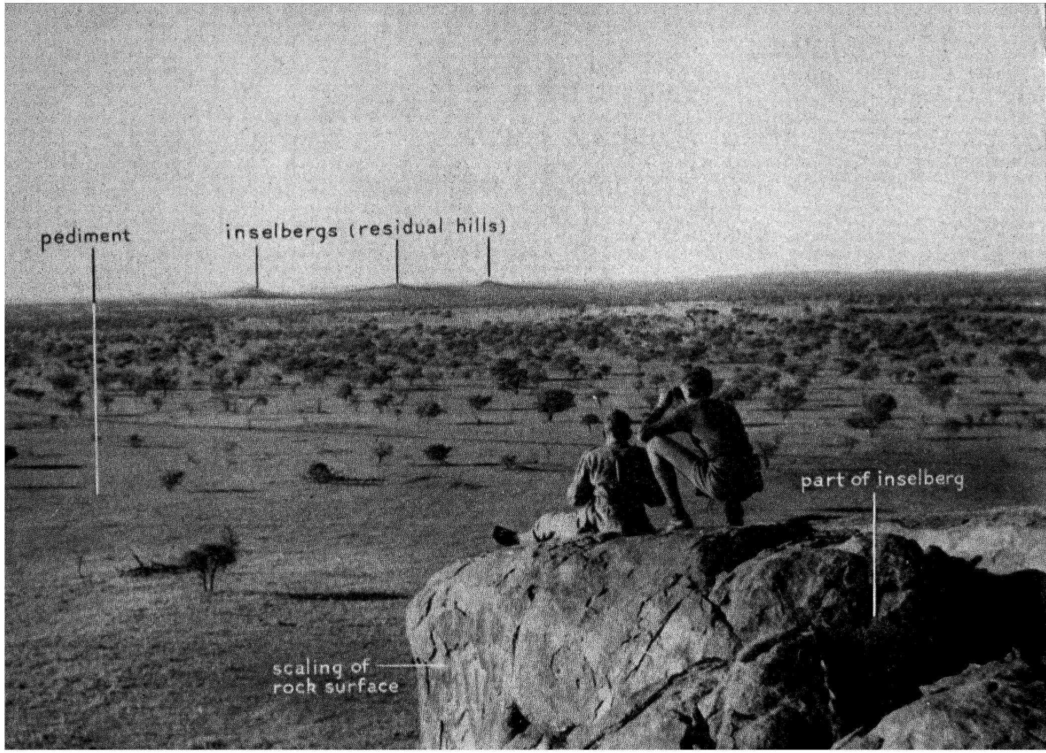


Plate 34 PEDIMENTS IN THE INTERIOR OF AUSTRALIA, SOUTHWEST OF ALICE SPRINGS. The gentle slopes of the pediments are covered in mulga scrub, while the steeply rising inselbergs display much bare rock which is undergoing mechanical weathering. Compare Plate 3, which shows a physically similar scene in central Africa.

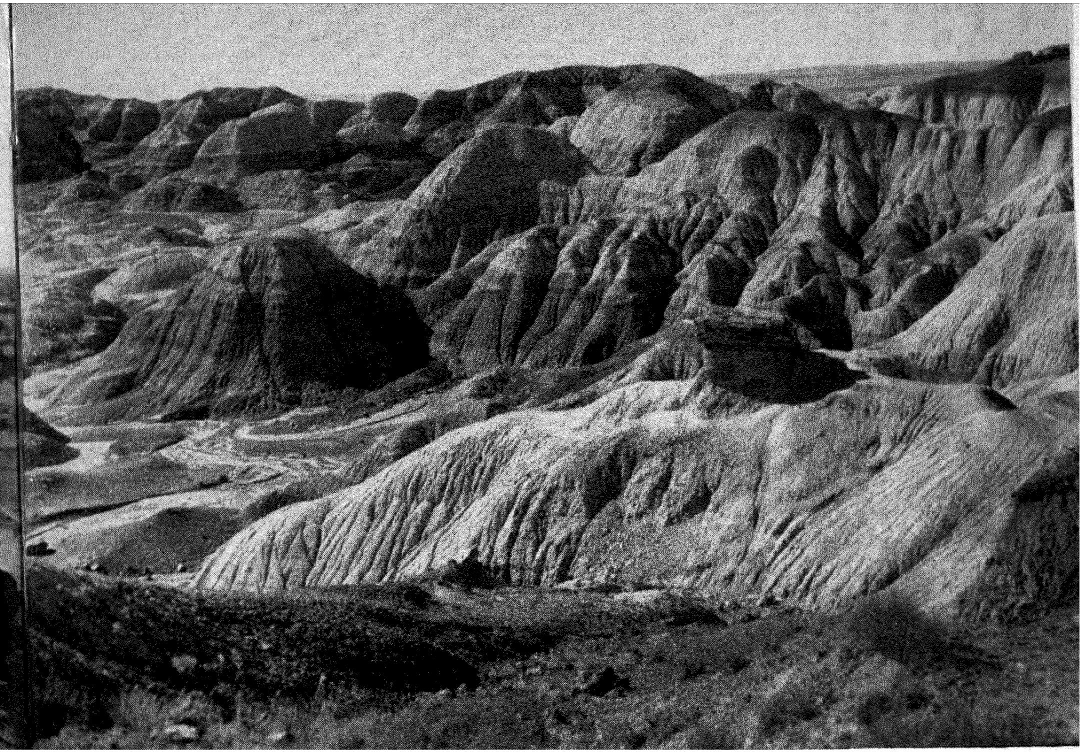


Plate 35 BADLANDS IN ARIZONA. Rainwater running over the surface has cut multitudes of gullies into the clayey rocks, which are being swiftly and severely eroded. Soil has scarcely any time to form, and cannot lodge on the steep slopes or withstand the repeated wash of water. Note that even where there is soil the vegetation is sparse ; the climate of this area is distinctly on the dry side.

vegetation binds the soil. Only if the land is laid bare can the wind raise large amounts of dust. Gullying, however, can be very severe indeed.

Landscape types. Two kinds of country are widespread in regions of semi-arid climates :

(i) pediments (ii) badlands

Both are shaped mainly by running water, and both are influenced by the thin cover of vegetation and by the convectional nature of the rainfall.

(i) *Pediments* (Pl. 34). Pediments are the vast, gently sloping land surfaces typical of so much of central Africa. They are shaped by floodwater. When heavy thunder-rain occurs the whole countryside is flooded to a depth of feet. It is eroded as a whole, instead of along the separate lines of river valleys. The wide pediments curve gently away from the sharply upstanding inselbergs (residual hills) which have so far resisted erosion. The scene in Plate 34 is in Australia ; the rock in the foreground is part of an inselberg, and others appear on the skyline in the far distance, beyond the broad, subdued surface of the pediment.

(ii) *Badlands* (Pl. 35). Where gullying is very severe the whole landscape can be cut into a multitude of small valleys. Country of this kind makes very bad going—hence the name badlands.

Soil erosion. Once a gully starts to form it is very difficult to stop its growth. Huge areas in Africa and in the U.S.A. have lost their soil through the formation of gullies. The damage has not by any means been confined to the regions of semi-arid climate, athough the danger is greatest there.

Where the natural vegetation is sparse or poor, as in all semi-arid regions, another danger may threaten. If the land is broken by ploughing, or if the grass is destroyed by over-grazing, the wind may attack the exposed soil. In dry seasons the soil may be swept entirely away, as in the Dust Bowl disaster in the U.S.A. There, in the nineteen-thirties, a vast belt of land stretching from the Dakotas to Texas experienced severe drought. Hundreds of thousands of farms were ruined by wind erosion.

6 The work of wind in other climates

Transport, erosion, and deposition by wind are most effective in dry climates. But the wind can pick up, carry, and lay down sand and dust wherever the surface is unprotected by vegetation or moisture. The loess sheets formed round the edges of the ice-caps have already been described. At the present time wind action is noticeable in certain coastal districts in humid areas. Where a sandy foreshore is exposed at low tide belts of dunes can form along the coast. They often take the shape of confused hummocks of sand.

Some coastal dunes move inland. The Culbin Sands of the Moray Firth were long out of control, and huge quantities of loose sand moved in, overwhelming fields, farms, and villages. These dunes are now being stabilised by thatching and planting. On the Biscay coast of France the moving sands of the Landes were blown far inland by the turbulent, onshore westerlies ; but the movement was checked by the planting of grasses, and grassing-over was followed by the planting of conifers. The Landes have been valuable forest land for many years now. Along the low coasts of Holland, Belgium, and northern France the coastal dunes are still apt to become unstable ; if bare sand is exposed to the wind it is blown away, and the dune-belt is occasionally broken through by the sea during gales.

Topics for discussion

1 If you live near a seashore, study the effect of the wind in moving sand. If there are dunes, make a sketch-map to show their distribution.

2 At the present day, dust blown out of the Gobi Desert falls as loess in the Hwang-ho basin. Explain why sheets of loess were widely deposited in Europe during the Ice Age.

3 Examine the gullies found, e.g. on a spoil-heap or in a sand-pit. Draw a sketch-map to show a gully, marking the area which is being eroded and that where material is deposited. What feature is made by the deposited material ?

4 The films known as 'Westerns' are set in semi-arid regions. Explain why this is so, and describe the kind of landscape which is usually shown in such films.

5 Use a work of reference to discover areas where soil erosion is severe at the present time. Is it true to say that soil erosion is typical of dry rather than of wet climates ?

6 The rainfall of arid and semi-arid regions comes typically from thunderstorms. Why is this, and why are the storms sometimes very heavy indeed ?

7 Agricultural land in the Fens is sometimes subject to wind erosion. Explain this circumstance, and say why the rest of the country does not suffer similarly.

Chapter Twenty

CONCLUSION

At the end of this account of physical geography it is appropriate to consider the relation of this part to the subject as a whole. Physical geography is concerned with describing and explaining part of the environment in which men live; there is another part—the social environment—which is best studied separately.

In many ways the physical environment indicates what cannot—and what can—be done with the land, with a varying effort and at a varying cost. It was said at the beginning of the book that climate prevents the cultivation of certain crops in certain regions. Conversely, some climates are well suited to the growth of a particular range of plants. It does not follow, however, that such crops will be grown, however suitable the climate may be. Within the bounds of climate there are narrower limits fixed by other factors. We have seen that the development of the tropical grasslands is hampered by inaccessibility; numerous other examples of the same drawback would be easy to find. Every single region, moreover, has its individual history. Its inhabitants have developed on their own lines, evolving their own ways of life. Cultivation on the alluvium of the Hwang-ho valley produces grain crops mainly for the farmers themselves—that is, subsistence cultivation is practised

—whereas on the alluvial plain of the Mississippi large amounts of cotton are grown for export—cash cropping is dominant. Again, the same region may have widely different possibilities for different groups of people. The Middle Eastern deserts offer to their native inhabitants farmland where there is sufficient water and poor grazing where there is little or none. Europeans and North Americans look there not for food but for oil. Throughout the world different groups of people have reacted in different ways to the problems and possibilities of their geographical environment.

What is true of the climate in this respect is also true of the form of the ground. Within the small area of the English lowlands we have noted that separate regions of scarpland have contrasted patterns of rural settlement. The physical background is the stage where man's activities are carried on ; the actual form of those activities depends on the inhabitants themselves. It is, of course, impossible to mine coal where the ground contains none, but it is entirely possible for existing resources of coal—or of any other mineral—to be neglected. In describing the geography of a given region, account must be taken not only of the climate, the form of the ground, the mineral resources, the natural water supply, and the nature of the soil, but also of the mode of life of the people who live there.

At the same time it is true to say that some regions are more favoured than others and have much to give their inhabitants. It is the task of physical geography to describe the character of the setting of man's life, advantageous or adverse as it may be.

One most important point should always be borne in mind. The physical environment changes so slowly that it seems permanent, but man's adaptation to it and use of it can change very rapidly. A hundred years ago Europeans who entered the tropical rain-forest ran the risk of disease and death ; today, thanks to preventive medicine, the risks are greatly reduced. Wheat cultivation in Canada has spread northwards, into areas where wheat could not formerly be grown, because new strains have been developed which can ripen in the short summer season. Oilfields newly developed in the Middle East and in South America have brought wealth to poor countries. In ways such as these geography is constantly changing.

The changing value of a particular geographical environment is not always a change for the better. London arose as a small riverside town with natural harbours in two small creeks. It has long outgrown the original site, and the little inlets are today of no significance whatever. The high tides of the estuary helped ships to come up-river, and the enormous capital developed round the old town—now the City of London. But for many years the Port of London has suffered from traffic congestion, both on land and in the river, made worse by fogs which the capital itself pollutes. Part of its trade and passenger services has been diverted to outports nearer the sea.

Here, as in all other environments, we see that the character of the land, the climate, and the changing pattern of human affairs raise difficulties which are never completely solved. Properly studied, physical geography makes it possible to appreciate the kind and the severity of the environmental problems that face mankind the world over.

Postscript

Many of the topics suggested above for exploration and discussion relate to your local district. This is where the study of physical geography should begin. Wherever you live, there is a very great deal to be found out about your home area, and many subjects will suggest themselves in addition to those already given.

A word of caution is necessary on the matter of pits and quarries. Where working is going on, permission to visit the site must always be obtained in advance from the owners. Some disused workings are dangerous—for instance, the face may be unstable. These are to be avoided. All geologists, who spend their lives in the study of rocks, are trained not to take unnecessary risks; and a beginner should always take the greatest of care in the field.

The best sections of rocks are usually those found at the seashore. Even here, however, it should be remembered that some cliffs are liable to collapse, and attention should be paid to warning notices.

Local examples of physical features are not to be despised because they are small—on the contrary, small features are often the easiest to study and to understand. They are no less authentic for being tiny, and moreover their development is often rapid, so that their construction or erosion can be observed without difficulty.

Although physical features can be studied for their own sake, the whole aim of this book is to make a knowledge of the Earth's surface useful in geography as a whole. With this principle in mind, one should relate the physical features of a given district to the quality of the land and to the use to which the land is put. It is safe to say that in any area, no matter where, the quality of the land varies with the form of the ground, so that there is a connection between landform and land use. It is this connection which should be sought in the field.

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